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ANALYSIS OF THE IMPACT OF PHASE ARRANGEMENT ON DURTION AND PERFORMANCE OF CAPITAL PROJECTS

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ANALYSIS OF THE IMPACT OF PHASE ARRANGEMENT ON DURATION AND PERFORMANCE OF CAPITAL PROJECTS

by

Hyeon Yong Park

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Dedication

To my wife, Jinhee, and my son, Hayul:

Thank you for teaching me what unconditional love and immeasurable joy are.

You will always be my proudest accomplishment.

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Completing my Ph.D. at the University of Texas at Austin would not be achieved without support and guidance from many people who were involved in my doctorate study.

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The University of Texas at Austin, 2017

Supervisors: Carlos H. Caldas and Stephen P. Mulva

In today's construction industry, projects continue to get larger and more complex than ever before. Meanwhile, project owners demand early completion of their projects, motivated by the desire to attain the first-mover advantage that heavily presses on the construction business. Within these circumstances, establishing project schedule that is reasonably certain to bring a project to completion on time or sooner requires a thorough understanding of how project schedule has been implemented. Phase arrangement used in this research is defined as the relative position and sequence of phases that encompass the project's development life cycle, namely: planning, detailed engineering, procurement, construction, and startup. A thorough understanding of phase arrangement can supply the basis to create preliminary project schedule early in the planning phase. The primary goal of this research is to characterize and identify patterns of phase arrangements and to measure their impact on duration and performance outcomes. Based on the quantification analysis of project schedules with consideration of their influential project characteristics, phase arrangements of the project development life cycle were characterized. Eleven unique pairwise and fifteen triple–wise patterns of phase arrangement that were employed by capital projects were identified and documented in this dissertation. Due to small sample size, comparisons of all patterns could not be conducted. Nonetheless, several statistically significant findings were observed specifically for projects that initiated early procurement involvement prior to planning, in terms of project duration and performance outcomes. This research contributed to the body of knowledge in two main areas. The first contribution is the characterization of phase arrangements to provide an analytic framework for analyzing project schedule at the phase level. The second contribution is that the impact analysis results of phase arrangements on duration and performance outcomes provide practitioners and researchers opportunities to acknowledge that phase arrangement and patterns of concurrency become an important consideration in planning and executing capital projects.

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CHAPTER 1: INTRODUCTION

1.1 RESEARCH MOTIVATION

In today's construction industry, projects continue to get larger and more complex than ever before. Meanwhile, project owners demand early completion of their projects, motivated by the desire to attain the first-mover advantage that heavily presses on the construction business (Hastak et al., 2008). Such demands by owners are necessary not only to stake a significant position in the growing market but also to sustain their existing market share. The confluence of these two circumstances makes it difficult for project managers/schedulers to establish a project's schedule early on as much as it makes it complicated to manage project execution effectively. To establish a project schedule that is reasonably certain to bring a project to completion on time or sooner requires a thorough understanding of how project schedule has been implemented.

Phase arrangement used in this research is defined as the relative position and sequence of phases that encompass the project's development life cycle, namely: planning (front-end planning; FEP), detailed engineering (engineering), procurement, construction, and startup. The traditional approach is that the five phases should be positioned sequentially as one finishes the next commences. That is, the engineering phase starts only if the planning phase finishes. In this context, a way to shorten the overall project schedule is to compress each phase duration. Since fast tracking, the process of performing phases in parallel, was introduced, considerable attention has been given to scheduling and managing the engineering and construction phases to work simultaneously to reduce the overall project schedule. That is, the construction phase starts before the engineering phase finishes. In this context, the project schedule is shortened to allow concurrency between two phases by starting a succeeding phase early before a predeceasing phase finishes. The key to successfully accomplishing this approach is to make sure that the predecessor is mature enough to convey its information to the successor. Figure 1.1 represents the phases with their typical activities as defined by the Construction Industry Institute (CII).

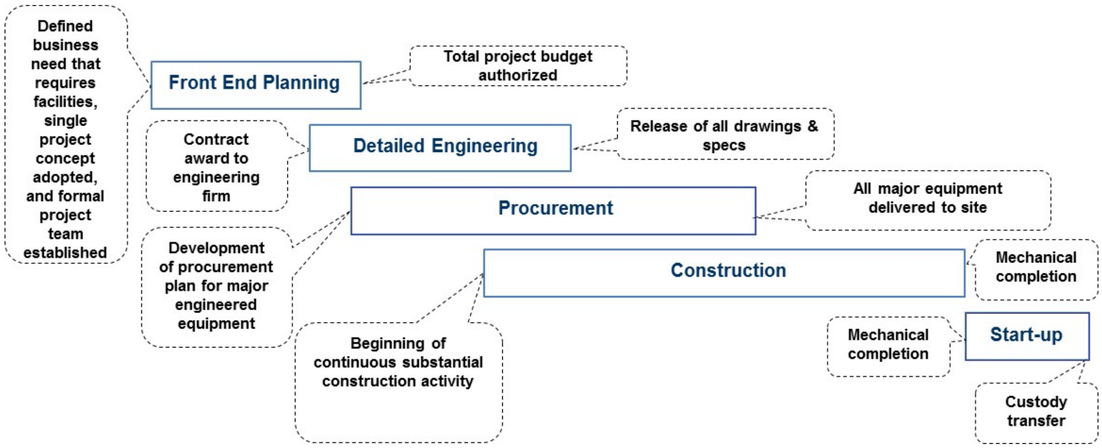


Figure 1.1 Phase Process and their typical activities (CII)

Concurrency, a core element of concurrent engineering and the fast-tracking technique has played an important role in shrinking project schedules for decades. A significant amount of research has been conducted in this area: a study of activity characteristics (Krishnan et al., 1997), a study of strategies for implementing concurrency on dependent design activities (Bogus et al., 2006), and a study of evaluating the effectiveness of concurrency in the engineering phase (Grèze et al., 2014a). Most studies have focused more on concurrency at the activity level in the design/engineering phase as a key to shortening its duration. Less attention has been given to concurrency at the phase level. Specifically, less interest has been provided on understanding how the phases interactively link together and what consequence that has on the project schedule.

With this consideration, this research explores actual schedule data of industrial capital projects submitted to the benchmarking programs at CII. By analyzing the phase-level schedule data, this research intends to present explicitly: 1) how the phases employed in industrial projects are arranged, and 2) how various phase arrangements influence duration and project's performance outcomes. By exploiting its analytical process and outputs, a better understanding of a high-level project schedule data is achieved.

1.2 POINT OF DEPARTURE

This research originated from a simple question. The question was to identify the average percent completion of the engineering phase prior to the construction phase start in heavy industrial capital projects. An initial data analysis showed that the average percent completion of the engineering phase before the construction phase start falls between 39% and 90% by various project characteristics. In detail, the average percent completion is between 63% and 90% by project delivery method, between 50% and 85% by project nature, and between 39% and 86% by project size. Those results indicate that most heavy industrial projects begin fast tracking the construction quite early before the engineering phase has finished. The question was then expanded to see how the concurrency between phases influences the project duration. The following describes the results of the data analyses for this question.

Figure 1.2 shows examples of what often happens in industries such as oil and gas, pharmaceuticals, manufacturing and so on. Figure 1.2 depicts two actual project' schedules with the same project type (Chemical Manufacturing) and nature (Grass Roots). Both reached beneficial production within 2.5 years after the strategic planning was initiated. The first distinctive difference between the two projects is that the size of the project on the left (project A) is five times larger than the project on the right (project B): \$257MM and \$48MM respectively. The second difference, excluding the duration of the construction phase, was that the project A represents extensive concurrency between the engineering and construction phases, while project B represents limited concurrency between them. If project A had been executed with the same limited concurrency as project B, it would have spent an additional year to reach beneficial production, meaning that the owner would potentially lose a year of profit. This illustrates that the level of concurrency is a major factor influencing the overall duration.

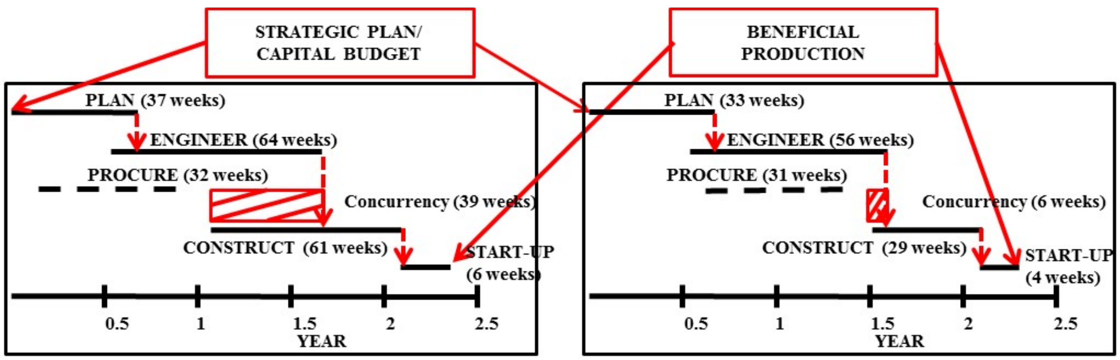


Figure 1.2 Effect of Concurrency on Duration

Figure 1.3 represents the schedule difference between two groups of projects: the first schedule in blue represents a group of projects where the procurement phase starts earlier than the completion of the FEP phase, whereas the second schedule in red displays a group of projects where the procurement phase starts after the completion of the FEP phase. Each project cost was normalized to $250MM based on the log relationship between cost and schedule, and each project duration was adjusted accordingly. Interestingly, the first group was complete 35 weeks earlier than the second group with the later procurement phase start time. Another key aspect of Figure 1.3 is that a group of projects in red has a lag (10 weeks on average) between the FEP and engineering phases, indicating that there is an opportunity for 10 weeks of schedule reduction if seamless progress were achieved.

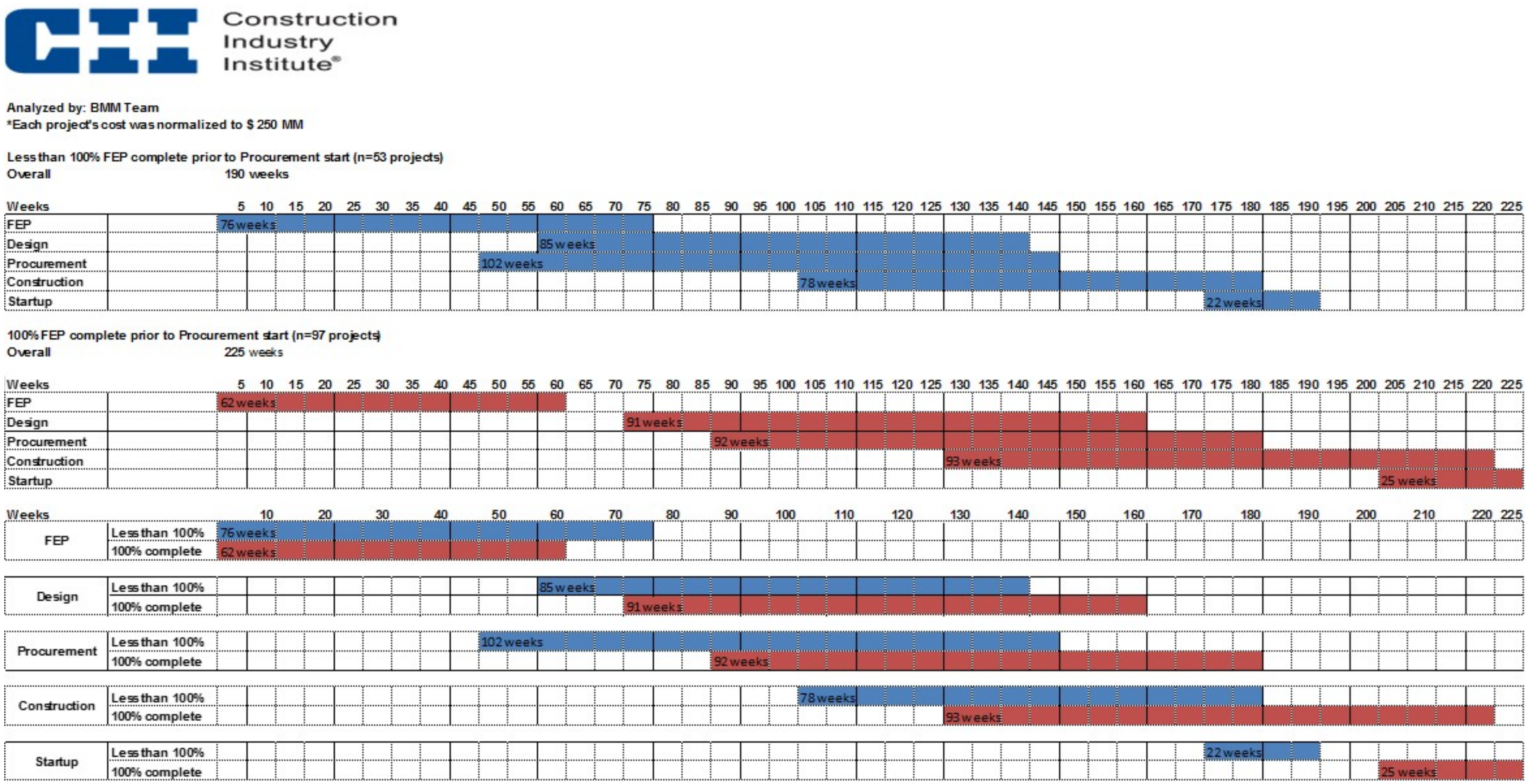


Figure 1.3 Effect of Phase Arrangement on Duration

1.3 RESEARCH OBJECTIVES

The purpose of this research is to analyze the impact of phase arrangement on duration and the performance of capital projects. Specific objectives include:

1) Characterize and quantify the phase arrangement and duration amongst phases of the project development life cycle with the consideration of various project characteristics
2) Identify and quantify patterns of pairwise/triple-wise phase arrangements employed in phases of the project development life cycle
3) Analyze impact of phase arrangements on duration and project's performance outcomes

1.4 RESEARCH QUESTIONS

The following research questions are established to meet the research objectives.

1st Research Question: How can project development life cycle phase arrangement and duration be quantified by various project characteristics?

The first research question is intended to characterize and quantify phase arrangement of the project development life cycle by analyzing schedule data provided by the industrial projects submitted to CII. The phase arrangement represents the relative position of phases in a project development life cycle with each phase's duration, its starting time, and finishing time. Once the phase arrangement is quantified, this question is also to test whether the project characteristics (such as industry group, project type, project size, and project nature) influence the phase arrangement.

2nd Research Question: How can patterns of pairwise/triple-wise phase arrangements be quantified and what are the most common patterns of phase arrangements employed in the project development life cycle?

The second research question is aimed to identify and quantify patterns of pairwise/triple-wise phase arrangements by grouping two/three phases respectively with consideration of each phase's duration, starting time and finishing time. That is, the pairwise phase arrangement represents the relative sequence and duration of the two phases. This research question is also to determine the frequency of the patterns employed in the project development life cycle. For example, the number of cases where the procurement phase starts before the engineering phase finishes will be illustrated. Lastly, the phase patterns used by various project characteristics will be presented.

3rd Research Question: How does each pair /triple of phase arrangements influence their duration and project performance outcomes?

The last research question is designed to support analysis of the impact of pairwise/triple-wise phase arrangements on duration and performance outcomes under the various project characteristics. For example, whether various phase arrangements differentiated their combined durations or the schedule growth is measured. When the durations of phase arrangements are tested, which phase arrangement had a shortened or lengthened duration is the focal point of analysis. For performance outcomes, which phase arrangement had an improved performance is the point of interest. The primary hypothesis is that a particular phase arrangement has a shortened duration or improved performance.

1.5 Research scope and delimitations

This research explores how different phase arrangements are behaved in the various project characteristics and documents how these various phase arrangements influence duration and performance outcomes. As a result, activity-level schedule analysis is out of scope of this research. Furthermore, this research does not represent how to shrink the project schedule; rather, it points to phase arrangements that correspond to shortened duration for given criteria and therefore obtain improved performance outcomes.

This research focuses on quantification of the project schedule in capital projects from the planning phase to the startup phase. Operations and maintenance after project completion is excluded. The project data used by the research were extracted from the CII Benchmarking and Metrics (BM &M) database. Only owner industrial type' projects were included because contactors' participation in the planning and startup phase is limited. The project data are comprised of projects with a total project cost greater than \$10MM USD in Chicago 2015 adjusted dollars. Grass Roots, addition, and modernization are considered as the project's nature. Furthermore, this research adapted the categorization of various project types suggested by Watermeyer (Watermeyer, 2002) and used in a study by Liao (Liao, 2008) on engineering productivity. As they suggested, project types in heavy industrial projects should be categorized according to process and non-process, rather than individual project type. Light industrial projects are grouped to include pharmaceutical manufacturing, laboratories, and other light industrial projects accordingly.

1.6 ORGANIZATION OF DISSERTATION

This dissertation consists of eight chapters. Chapter 1 presents the research motivation and objectives along with the research questions. It also includes scope of the research. Chapter 2 provides the research background, identifying gaps in the literature review and detailing the need for this research. Chapter 3 describes the research methodology that presents how to collect data through the CII BM&M database, how to analyze the schedule data for each research question, and how each research question is connected to fulfill the research objectives. Chapter 4 presents data analysis results for research question 1, the phase arrangement employed in the project development life cycle. Chapter 5 presents the frequency of occurrences of patterns of phase arrangements to address the research question 2. Chapter 6 presents data analysis results for research question 3 with a focus on the impact of phase arrangements on duration and performance outcomes. Throughout chapter 4 to chapter 5, the results are divided into two sub-chapters: heavy industrial projects and light industrial projects. In Chapter 6, the results are presented by phase combinations to explicitly illustrate the impact of phase arrangement on duration and performance outcomes. Chapter 7 demonstrates how the methodological framework can be applied with consideration of an external factor that possibly affects duration and performance. Chapter 8 summarizes the findings based on the research questions and provides an academic and practical contribution. This chapter also covers limitation and suggests directions for future research.

CHAPTER 2: RESEARCH BACKGROUND

This chapter presents findings from the previous studies with a specific focus on processes and practices for managing and controlling project schedules. Some processes and practices introduced in this chapter may not be related solely to schedule. Briefly, this chapter is organized into three sections. The first section reviews the processes that have contributed to enhance managability of project schedules. The second section presents various practices for schedule reduction. The last section summarizes the finding and gaps in the existing body of knowledge.

2.1 PROCESS FOR PROJECT SCHEDULE MANAGEMENT

2.1.1 Stage (phase) Gate Process and phase process defined by CII

According to Cooper (2008), "*a Stage-Gate Process is a conceptual and operational map for moving new product projects from idea to launch and beyond*." As shown in Figure 2.1, the process consists of a series of stages and gates. Each stage represents each process required to launch a product to market, and each gate is the point where a go or no go decision is made. In detail, every stage contains its scope, objectives, activities, deliverables and functional responsibilities to lower uncertainty and risks that may induce delay or over budget. Every gate may contain criteria to make a decision, along with list of deliverables. Interestingly, the process focuses squarely on the planning of the product even if the process covers a product's development life cycle. Three of six processes, e.g., discovery, defining market's need or generating idea, scoping, and building a business case in Figure 2.1, is the evidence of it. The important thing to note is that the stage gate process does not imply the stages in a sequential manner as they appear in Figure

2.1 (Cooper, 2008; Thamhain, 2000). Rather, inside of each stage, tasks or activities are allowed to perform in parallel, or with some extent of concurrency.

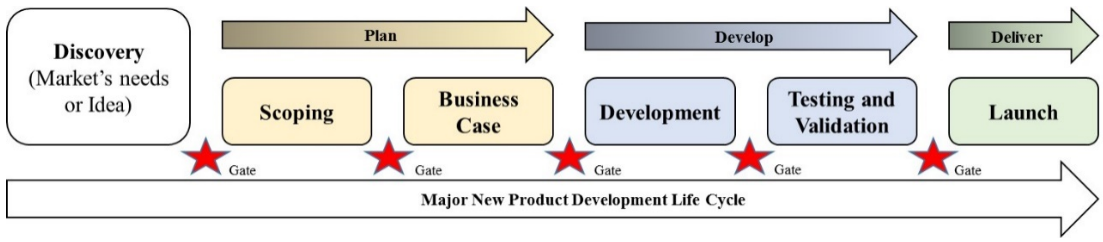


Figure 2.1 An Overview of a Typical Stage-Gate Process (Adapted from Cooper, 2008)

Compared to the stage Gate Process, the phase process, defined by CII, puts more emphasis on the execution stage of the product development. The execution stage is well-segmented based on participation and functionality of the participants or stakeholders in each to phase from engineering to start up, along with their typical activities (refer to Figure 1.1). In addition, the phase definitions function to normalize project data and enforce consistency across CII. Project schedule data is submitted and validated through the CII BM&M programs based on the phase definitions and its typical activities. It may be noted that the phases of the phase process are fragmented by the unique roles and functions performed by their participants, but the five phases are fully integrated to deliver a final capital project. It allows performing phases to be sequential, parallel, or concurrent to some extent. Table 2.1 presents the phase definitions defined by CII in detail.

Table 2.1 Project Phase Definition

Project Phase	Start/Stop Activities	Typical Activities & Products
Front End Planning Typical Participants: • Owner Personnel • Planning Consultants • Constructability Consultant • Alliance / Partner	Start: Defined Business Need that requires facilities Stop: Total Project Budget Authorized	• Options Analysis • Life-cycle Cost Analysis • Project Execution Plan • Appropriation Submittal Pkg. • P&IDs and Site Layout • Project Scoping • Procurement Plan • Arch. Rendering
Detailed Engineering Typical Participants: • Owner Personnel • Design Contractor • Constructability Expert • Alliance / Partner	Start: Design Basis Stop: Release of all approved drawings and specs for construction (or last package for fast-track)	• Drawing & Spec Preparation • Bill of Material Preparation • Procurement Status • Sequence of Operations • Technical Review • Definitive Cost Estimate
Procurement Typical Participants: • Owner Personnel • Design Contractor • Alliance/Partner	Start: Procurement Plan for Engineered Equipment Stop: All engineered equipment has been delivered to site	• Supplier Qualification • Supplier Inquiries • Bid Analysis • Purchasing • Engineered Equipment • Transportation • Supplier QA/QC
Construction Typical Participants: • Owner Personnel • Design Contractor (Inspection) • Construction Contractor and its subcontractors	Start: Commencement of foundations or driving piles Stop: *Mechanical Completion*	• Set Up Trailers • Procurement of Bulks • Issue Subcontracts • Construction Plan for Methods/Sequencing • Build Facility & Install Engineered Equipment • Complete Punch list • Demobilize Construction Equipment
Start-up / Commissioning Note: Not usually applicable to infrastructure or building projects Typical Participants: • Owner personnel • Design Contractor • Construction Contractor • Training Consultant • Equipment Suppliers	Start: *Mechanical Completion* Stop: Custody transfer to user/operator (steady state operation)	• Testing Systems • Training Operators • Documenting Results • Introduce Feedstocks and Obtain First Product • Hand-off to User/Operator • Operating System • Functional Facility • Warranty Work

Despite differences in the level of detail describing phases (stages), the phase process adapts the same functional processes, used in Stage Gate Process, in the front-end planning phase. At the end of the front-end planning, total project budget is authorized and the project is sanctioned. The front-end planning is composed of three sub phases: feasibility, concept development, detailed scope definition, as shown in Figure 2.2. Within these three sub-phases, internal funding assessments may occur (CII, 1994). However, once the project is in execution, there is no defined gate to determine a go/no-go decision so that a project is less likely to be terminated as the execution progresses. The size of the arch in each phase shown in Figure 2.2 represents the corresponding effort and expenditure, along with the level of influence by the phases in project life cycle. The level of influence, or "*a company's ability to affect the outcome of a project*" (CII, 1994), considerably goes down as phases progress, while the level of effort required and expenditure continuously increases. Interestingly, compared to other similar definitions, the phase process is not allowed any extent of concurrency between the construction and startup phases by their definitions: the ending activity of the construction phase and the starting activity of the startup phase is mechanical completion. However, when taking the objectives of the startup phase and increased time to market conditions into consideration, the definition needs to be flexible to allow for some extent of concurrency.

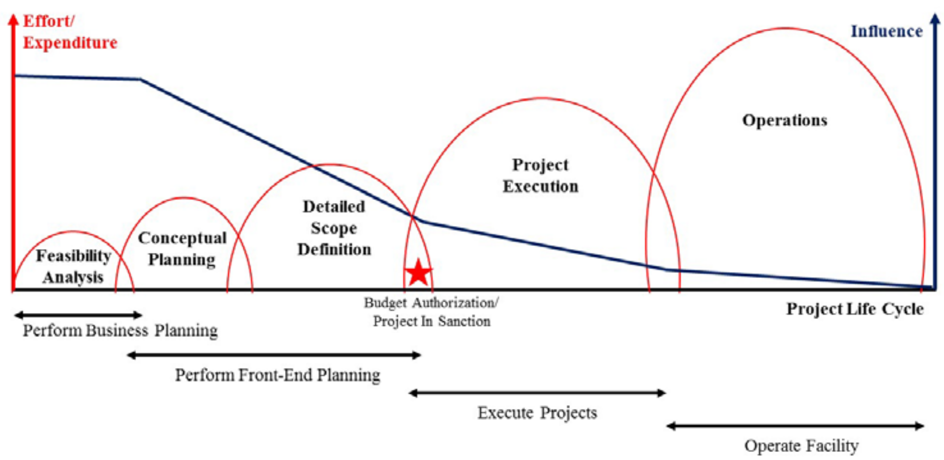


Figure 2.2 The Level of Effort and Influence for Phases in the Project life cycle (Adapted from CII (1994))

2.1.2 Agile Project Management

Under reasonably stable market condition, the waterfall (linear) process played major role in the 1970s and 1980s (Thamhain, 2000). However, due to dramatic changes in market conditions and environment, the linear process needed to be more sophisticated and flexible to accommodate adjustment.

The waterfall process, a plan driven process, was named after its sequential and cascading process flow. This process was well adopted in the manufacturing and construction industries, as well as in the software industry. Due to its rigidly framed process, it was found that it had a tendency to induce increased costs and lengthened duration when changes incur. Royce (1970) pointed out the major deficiency of the process model was when errors were discovered at the end of the process. If any change was found to be necessary, "*either requirement must be modified, or a substantial change in the design is required,*" which resulted in cost overrun, schedule delay, and quality deficiency. Nonetheless, most investment owners in industry still utilized this model.

Agile Project Management (APM) was introduced early in the early 2010s. Its distinct differences from the traditional waterfall model lie in its iterative, people-oriented process, and minimal upfront planning and documentation. Whereas, the traditional linear process strictly follows sequences: e.g., the test phase is only allowed to start after the building codes are complete. APM entails rapid planning and development by co-located stakeholders. APM can be classified as a proactive approach because it is responsive to changes by stakeholders and customers (Owen et al., 2006). This method is currently popular within the software industry, however, whether an application to construction projects where the engineering (design) and construction phases perform concurrently to a great extent is in question. Furthermore, the quantitative effects of agile project management need more study. Figure 2.3 shows comparative views of waterfall sequences and APM.

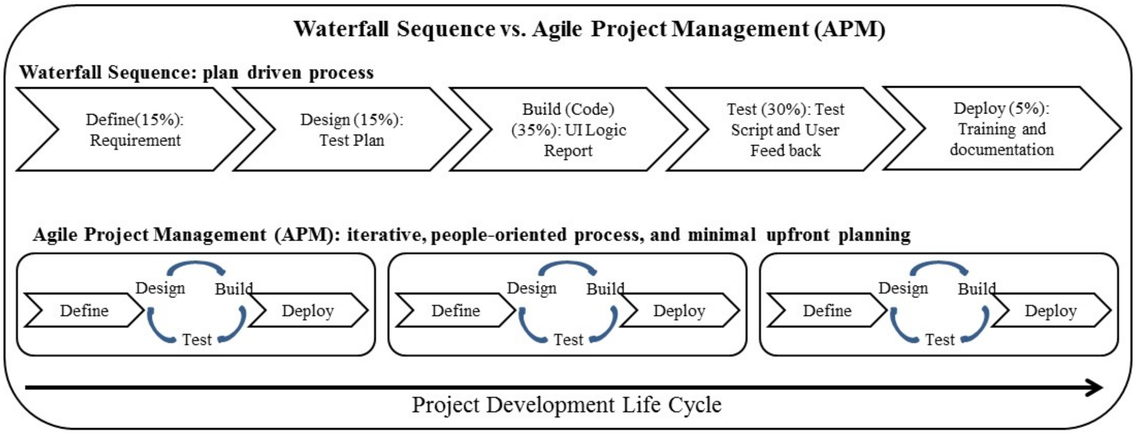


Figure 2.3 Comparative Views of Waterfall Sequences and Agile Project Management (Adapted from www.greenlinesystems.com/agile-software-development)

2.2 PRACTICES FOR SCHEDULE REDUCTION

2.2.1 Schedule reduction strategies by CII

2.2.1.1 Radical Reduction Techniques

Schedule compression techniques such as a crashing are used to shorten the project duration with an additional input of funds, whereas schedule reduction attempts to shorten the project duration without additional cost (CII, 1995; Gerk & Qassim, 2008). Over the past few decades, several research efforts have focused on identifying schedule reduction techniques. In a series of efforts to identify schedule reduction techniques, CII Research Team 41 (1995), Schedule Reduction, introduced five techniques that have a potential for reducing project duration, namely: freeze of project scope, constructability, concurrent engineering, use of electronic media, and cycle time analysis. For example, project scope freeze has the highest impact in the conception/definition phase and diminishes in impact as the project progresses. That is, without an early freeze of project scope during the planning phase, the project may keep suffering from continuing change to the project scope even after final budget authorization. This situation eventually results in extended project duration.

CII RT 193 (2004), Radical Reduction in Project Cycle Time, identified 10 top CII best practices, schedule reduction techniques, and management techniques. Interestingly, RT193 also found five valuable insights from case studies that would benefit radical reduction: blanket project agreement, clear alignment, developing a plan and working it, early advances in engineering, and having a SWAT team. The blanket project agreement is "*a purchasing agreement with pre-selected suppliers to eliminate time-consuming solicitation*." The goal of early advances in engineering is to release partially completed engineering deliverables to expedite procuring process in which long-lead equipment and material can be procured. These two insights amongst others presumably indicate the importance of input from suppliers and manufacturers early on in the project planning and engineering phases to accomplish project schedule reduction.

2.2.1.2 PEpC and cPEpC

Due to information dependency, the procurement phase has often been considered a subsequent phase after planning and engineering in capital projects. The more capital projects are fast-tracked to reduce schedules; the more research efforts are focused on the engineering and construction phases to maximize the impact of fast track. Unfortunately, this circumstance has caused practitioners to pay less attention to the procurement phase itself.

CII RT 130-1 (1998), Reforming Owner, Contractor, Supplier Relationship, proposed a strategic project delivery process, introducing the concept of “PEpC” (Procurement-Engineering-procurement-Construction). As it is named, the capital P indicates a phase (process) wherein complex engineered equipment, usually taking a long lead time and highly impacting on project performance are procured, before the (detailed) engineering phase starts. The lowercase p indicates a phase that procures the balance of the needed items. This approach emphasizes the importance of strategic sourcing of suppliers and manufacturers and leverages their ability to share their technological knowledge and expertise in the early project development life cycle. CII RT 211(2007), Effective Use of the Global Engineering Workforce, pointed out that to achieve successful completion of a fast track project on time, timely and accurate inputs from suppliers are key. This approach also implies that planning and procurement phases may lengthen to accommodate the concept, but the overall project schedule is reduced by procuring long-lead equipment early. This approach may require modifying some common beliefs, for example, that the procurement phase is a subsequent phase of the engineering phase; and that all phases in the project development life cycle are sequential in a series of phases: planning, engineering, procurement, construction, and startup.

In a recent publication, RT 311(2015), Successful Delivery of Flash-track Projects, introduced the concept of “cPEpC”, wherein the small c indicates the participation of specialty contractors in the preliminary conceptual design phase. The concept embraces the big P, defined by RT 130, and parallel engineering and construction, to achieve faster fast-tracking. However, the team did not specify how to implement those in a project. Rather, it suggested a tool helping determine a company’s readiness to undertake a flash track project and practices to overcome barriers to implementation.

2.2.2 Fast-Tracking and Concurrent Engineering

The fast-tracking technique was developed to meet the challenges and expedite project development process. Its development was associated with the increased construction cost in the 1970s, induced by the environmental changes such as increased technical complexity of projects and socio-economic pressures (Alhomadi et al., 2011; Fazio et al., 1988). Reduction of a project's overall schedule can be achieved by starting the construction phase before the engineering phase completes, that is, the construction phase starts with incomplete design information. Huovila et al. (1994) asserted that the fast tracking technique is "*a practically oriented approach, but with no solid conceptual or theoretical basis*." Furthermore, compared to the traditional linear process, lack of information such as from insubstantial quality or a restricted quantity of data, the designer necessarily increases assumptions for detailed design work, may produce compromises to project performance from poor design information (CII, 2007). Despite the challenges that come with an early start of the construction phase and less information available from the engineering phase, the fast-tracking technique have become a process norm in the construction industry.

Concurrent engineering was developed by the manufacturing industry for cycle reduction of the design phase in the product development (Bogus et al., 2005). Its ultimate goal is to reduce project development time by shortening the design process with application of some extent of concurrency. Considerable attention has been given to find the optimal extent of concurrency while mitigating the negative impacts of an overlapping activities (tasks) in the design process. In an earlier study, Loch and Terwiesch (1998) and Terwiesch (2002) developed an analytical model to search for an optimal extent of concurrency based on the relationship between concurrency and communication. In a more recent work conducted in the construction domain, Dehghan and Ruwnapura (2014) suggested an algorithm to find an optimal extent of concurrency while considering the amount of rework. Even if many researchers have studied various facets of concurrent engineering, most studies have focused in isolated activities in the detailed engineering phase (Dehghan & Ruwnapura, 2014). In addition, most ressearchers have acknowledged that increased concurrency raises the chance of rework or changes, ultimately resulting in project delay (Berthaut et al., 2011; Dehghan & Ruwnapura, 2014; Gerk & Qassim, 2008; Park, 1999; Roemer & Ahmadi, 2004).

2.2.2.1 Characteristics of Activities under Concurrent Engineering

To achieve effective schedule reduction, activities characteristics need to be evaluated. According to Prasad (1996), activities can be classified to four types of relationships: dependent, semi-independent, independent, and interdependent activities. In dependent activities, the succeeding activity needs to receive complete information from the preceding activity, whereas in independent activities the succeeding activity can start at any time without any information from the preceding activity. In interdependent activities, the two activities work in parallel and receive and transmit information simultaneously, whereas in semi-independent activities the succeeding activity can start by receiving partial information from the preceding activity. In addition, the degree of evolving risk, associated with the extent of concurrency, is slowed down as an order of interdependent, semi-independent, dependent, and independent activities (Bogus et al., 2005), shown in Figure 2.4.

According to Krishnan et al. (1997), activities can be characterized as evolution and sensitivity. Evolution refers to the refinement rate of information from a predecessor perspective, whereas sensitivity refers to the magnitude of effect on a successor activity to reflect the change that was triggered by a predecessor. To achieve significant schedule reduction can be achieved when a predecessor with a fast evolution meets a successor with a slow sensitivity (Bogus et al., 2005). Otherwise, the benefit from schedule reduction decreases with increased complexity.

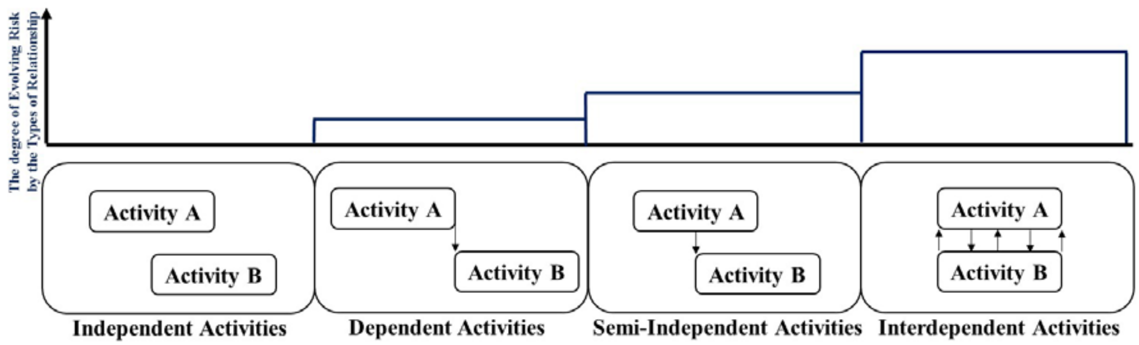


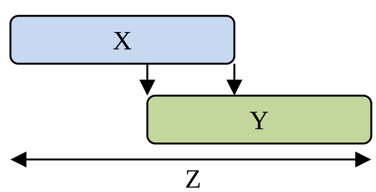
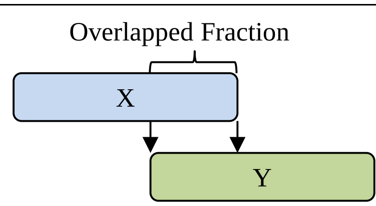
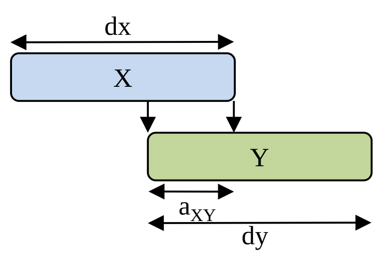
Figure 2.4 Four Types of Relationships and Their Degree of Evolving Risk (Adapted from Bogus et al., 2005)

2.2.2.2 Measurement

Table 2.2 shows a few examples of how to measure the concurrency between activities. Clark and Fujimoto (1991) developed the Simultaneity Ratio (SR) for measuring the amount of time spent on the engineering phase by looking at the level of concurrency between the process-engineering phase and the product-engineering phase. The authors pointed out that shortened time to market for Japanese automotive manufacturers in the 1960s was achieved by a higher level of concurrency between the two phases, compared to those in Europe and the United States of America. The strength of the SR is that it is simple to measure concurrency, but it is hard to capture the explicit extent of concurrency between two phases. If the metric score indicates 1, then the two phases are positioned sequentially, whereas if the metric score indicates 2, then the two phases are completely parallel. Dehghan (2009) implemented a metric to measure the degree of concurrency between two activities. The metric only reads the amount of time as an overlapped fraction between two phases without considering the durations of activities. Blacud et al. (2009)

and Greze et al. (2014b) suggested a metric capturing the fraction of time in the duration of the succeeding activity without considering the duration of the preceding activity. Even if these last two metrics consider the degree of concurrency between two activities, the degree of concurrency represents a portion of only one activity. Therefore, those metrics are unable to show the degree of concurrency in the overall duration of X and Y (Z in SR) and are limited to testing the effect of concurrency on the overall duration.

Table 2.2 Metrics used to determine the degree of concurrency

Authors	how to measure concurrency	Metrics/Definition
Clark and Fujimoto (1991)		Simultaneity ratio= (X+Y)/Z Where Z equals overall duration of X and Y
Dehghan (2009)		Degree of overlapping= (time duration of the overlapped fraction/total duration of the shorter activity) * 100
Blacud et al., (2009) and Greze et al (2014b)		a_{XY} = A fraction of the downstream (succeeding) activity duration where dx = duration of X and dy =duration of Y

2.3 SUMMARY

In this chapter, processes used in the construction industry, as well as other industries, to control and manage project schedule have been reviewed. Practices for schedule reduction were studied with a focus on two categories: 1) practices developed by

CII; and 2) widely accepted fast-tracking and concurrent engineering studies. Specifically, this chapter reviewed how previous studies characterize activities relationships and how to measure concurrency. It revealed that most studies in concurrent engineering focused on the extent of concurrency with respect to rework. The underlying assumption for those studies was that increased level of concurrency induces rework or change, resulting in compromised project performance. The goal was to find the optimal extent of concurrency without sacrificing project performance. It also illustrates that previous studies emphasize concurrency in isolated activities in the detailed engineering phase, rather than focusing on the concurrency in phases such as concurrency between engineering and construction phases.

It is clear that no one has applied phase arrangement and patterns of concurrency in the construction industry. Some patterns were found in the literature review but did not capture all other patterns used in capital projects. In detail, There has been comparatively less attention paid to how the phases behave, however. This forms the basis for the first research question to be addressed in this research with the introduction of the phase arrangement. The phase arrangement, used in this research, is defined as the relative position and sequence of phases that play out in the project's development life cycle. Activity relationships have served as a basis of study with respect to concurrent engineering, but little study has been conducted to investigate it within the phase level itself. That leads to the second research question. Lastly, there is little information available about the impact of various phase arrangements on project duration and project performance by utilizing actual project data. That drives the necessity of the third research question. To address the questions above, Chapter 3 presents how to tackle each research questions in detail.

CHAPTER 3: RESEARCH METHODOLOGY

An overview of the research process used for this research is provided in Figure 3.1. The first step of the methodology, development of research objectives and research questions was stated in Chapter 1. A background study with respect to schedule management and schedule reduction strategies was conducted in Chapter 2. The research design and a discussion of data collection and validation, along with the distribution of the collected project data, are presented in the subsequent sections. Procedures of the data analysis and statistical methods utilized are specified in the following sections.

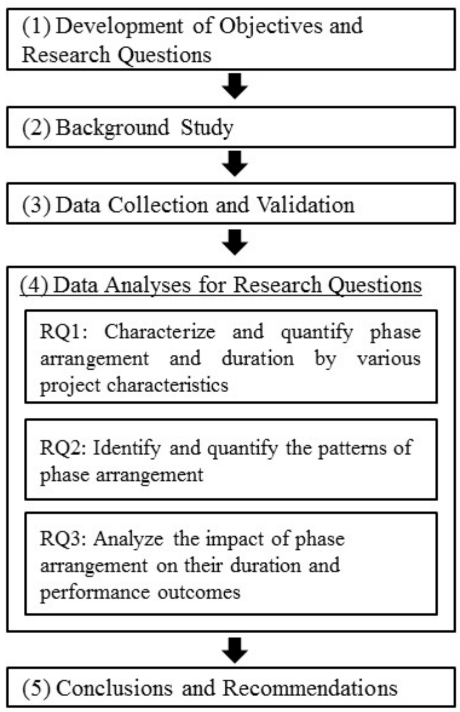


Figure 3.1 Research Process

3.1 RESEARCH DESIGN

This research was designed to analyze project's schedule dates and with that information to determine the following: 1) how each phase behaves within the overall schedule; 2) what patterns of phase arrangement exist and which pattern is empolyed in most common ; 3) how patterns influence duration and performance outcomes. To do so, this research adopted quantitative data analysis with use of descriptive and comparative studies. For the first two objectives, or research questions, descriptive statistics were used to present the results. For the last question, the results by comparison amongst various phase arrangements were explored.

3.2 DATA COLLECTION AND VALIDATION

3.2.1 CII Benchmarking and Metrics (CII BM&M)

For more than two decades, the CII BM&M program has collected capital projects data and developed CII survey questionnaires to effectively form a basis to benchmark a project against other projects having similar characteristics. The survey is composed of five major categories: project description, performance, practices, engineering productivity, and construction productivity. Various specialty versions of the questionnaires have also been released to accommodate specific purpose-programs: for instance, the Construction Owners Association of Alberta (COAA), pharmaceutical, and healthcare programs are among those developed for targeted industrial need. Among essential inputs garnered during the development of the questionnaires, the CII BM&M committee members have been indispensable. The committee is composed members who are multidisciplinary industrial experts, and academic professionals; they play a principle role in developing and reviewing the questionnaires. This research adopted the CII BM&M questionnaire version

10.3 to characterize phase arrangements and examine the effects of phase arrangement on duration and performance outcomes. The questionnaire is attached in Appendix.

In parallel with the questionnaires development, CII has devised and advanced the performance assessment system to collect project data efficiently. The performance assessment system, a web-based system, has been designed to accommodate the questionnaires and has reflected changes in the questionnaires over time. The major components of the system are characterized as data input, validation process, and output (key report) that contains project's benchmarked results. Project managers of participating companies initiate a project in the system by entering basic project information and inputting project data. The validation process involves a collaborative process between the project managers and benchmarking account managers at CII. The account managers are supposed to review and validate data by checking consistency with other submitted data and ensuring reliability and validity of the data. Figure 3.1 depicts the validation process of a submission from data selection to completion of the validation.

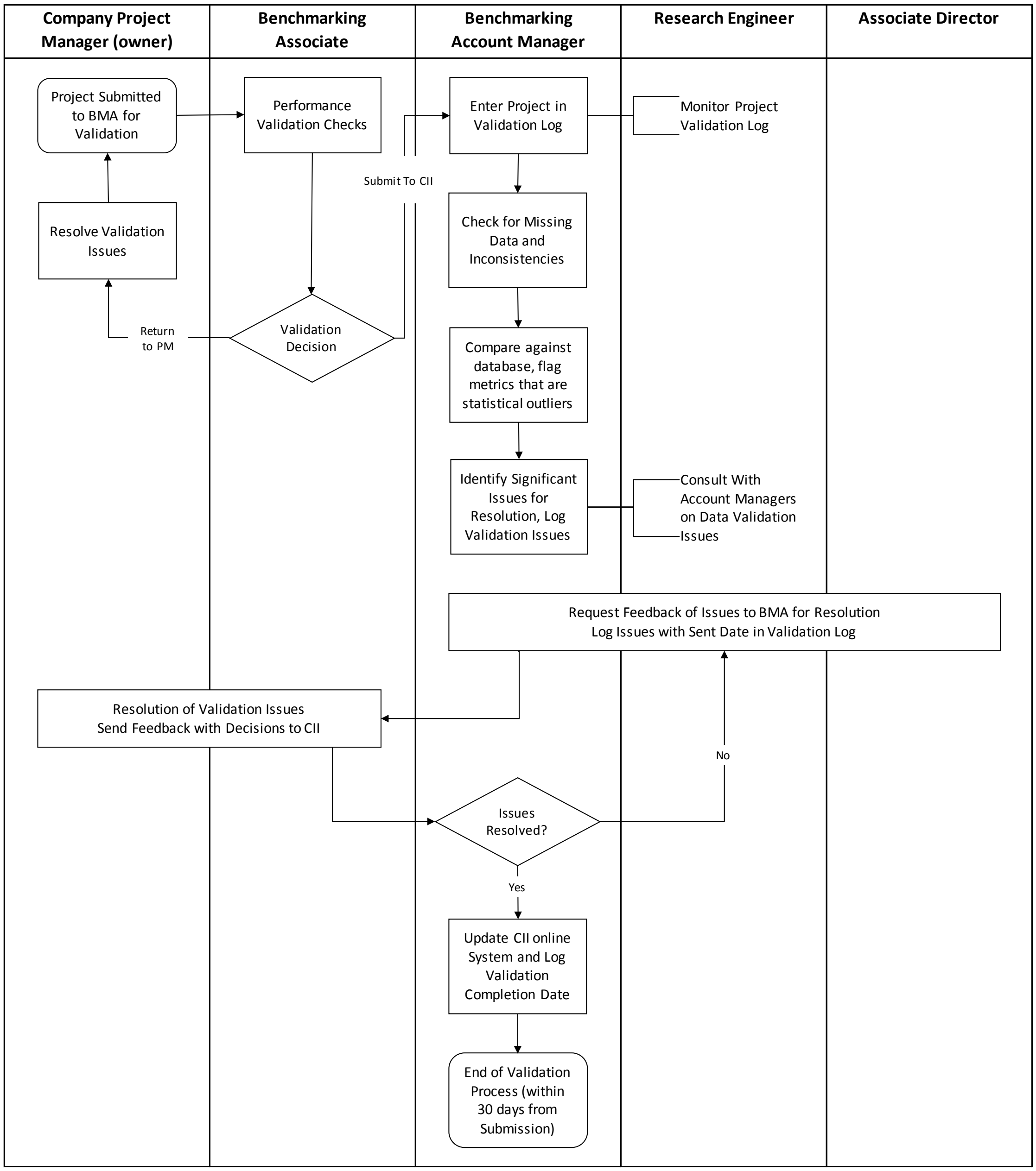


Figure 3.1 Validation Process

3.2.2 The Survey Instrument

The relevant parts of the questionnaire for this research are obtained from two sections: 1) general project description and 2) project performance outcomes. The general project description collects data related to project characteristics: industry group, project type, project nature, and project complexity. The project performance outcomes section is designed to collect data related to project cost and schedule, both of which consist of planned and actual data fields, as well as project outcomes and impact factors. In the schedule section, specifically, each phase's start and stop dates are collected to enable calculation of each phase duration and the total duration of a project. Table 3.1 presents how the questionnaire collects schedule dates. As shown in Table 3.1, the questionnaire is composed of baseline and actual schedules. According to the glossary of terms at CII BM&M, the baseline schedule indicates what it planned and approved schedule at the time of Project Sanction for owners. The execution schedule is aimed to calculate the total length of a project in its execution, which covers the engineering phase to the startup phase. The execution schedule is needed for the case where a project schedule dates are not separated by phases.

Table 3.1Questions to collect project schedule dates by phases in the questionnaire 10.3

	Baseline Schedule		**Actual Schedule**	
	Start **mm/did/ivy**	Stop **mm/did/ivy**	Start **mm/did/ivy**	Stop **mm/did/ivy**
Execution Schedule	______________	______________	______________	______________
	☐ NA ☐ Don't Know	☐ NA ☐ Don't Know	☐ NA ☐ Don't Know	☐ NA ☐ Don't Know
Front-end Planning (or FED)	______________	______________	______________	______________
	☐ NA ☐ Don't Know	☐ NA ☐ Don't Know	☐ NA ☐ Don't Know	☐ NA ☐ Don't Know

Table 3.1Questions to collect project schedule dates by phases in the questionnaire 10.3 (Continued)

	Baseline Schedule		**Actual Schedule**	
	Start **mm/did/ivy**	Stop **mm/did/ivy**	Start **mm/did/ivy**	Stop **mm/did/ivy**
Detailed Engineering	______________ ☐ NA ☐ Don't Know	______________ ☐ NA ☐ Don't Know	______________ ☐ NA ☐ Don't Know	______________ ☐ NA ☐ Don't Know
Procurement	______________ ☐ NA ☐ Don't Know	______________ ☐ NA ☐ Don't Know	______________ ☐ NA ☐ Don't Know	______________ ☐ NA ☐ Don't Know
Construction	______________ ☐ NA ☐ Don't Know	______________ ☐ NA ☐ Don't Know	______________ ☐ NA ☐ Don't Know	______________ ☐ NA ☐ Don't Know
Startup / Commissioning	______________ ☐ NA ☐ Don't Know	______________ ☐ NA ☐ Don't Know	______________ ☐ NA ☐ Don't Know	______________ ☐ NA ☐ Don't Know

Table 3.2 represents the definitions of metrics used for the data analyses of project performance outcomes. These metrics were adapted from the existing fundamental metrics used for benchmarking projects with other projects that have similar project characteristics in the CII BM&M. As displayed in Table 3.2., metrics used for measuring project performance outcomes in this research are categorized as schedule, cost, and change. All metrics used for the data analyses fall into one of two metrics groups. The first group includes metrics whose value indicates that lower or higher is better. i.e., growth metrics and change factor. The growth metrics compare the actual value to the planned value and the change cost factor metric that represents the proportion of value to a total value. The second group is composed of those that do not indicate lower or higher is better, i.e., phase duration and cost factors . Those factor metrics are similar to the change cost factor in

shape but lower or higher results are not necessarily better. This is mainly because there are no definitive studies to support the assertion that lower (or higher) duration factors indicates better performance in the project schedule.

Table 3.2 Definition of Performance Metrics

Performance Metric		Metric Definition
Schedule	Project Schedule Growth	$\frac{\text{Actual Total Project Duration - Initial Predicted Project Duration}}{\text{Initial Predicted Project Duration}}$
	Phase schedule Growth	$\frac{\text{Actual Phase Duration – Initial Predicted Phase Duration}}{\text{Initial Predicted Phase Duration}}$
	Phase Duration Factor	$\frac{\text{Actual Phase Duration}}{\text{Actual Overall Project Duration}}$
Cost	Project Cost Growth	$\frac{\text{Actual Total Project Cost - Initial Predicted Project Cost}}{\text{Initial Predicted Project Cost}}$
	Phase Cost Growth	$\frac{\text{Actual Phase Cost – Initial Predicted Phase Cost}}{\text{Initial Predicted Phase Cost}}$
	Phase Cost Factor	$\frac{\text{Actual Phase Cost}}{\text{Actual Total Project Cost}}$
Change	Change Cost Factor	$\frac{\text{Total Cost of Changes}}{\text{Actual Total Project Cost}}$

3.2.3 Project data Selection

Data from more than 3000 projects are included in the CII BM&M database in various stages of completion: in-progress, completion, submitted, and validated. Among those, less than 2300 projects data have been validated process. Even if all project data had been through the validation process, the data set would not necessarily be fit for this research. To fit the dataset required by this research, additional data scoping was necessary. Only data, submitted from owners, were selected (Sample size = 1411). The reasons for collecting owners' project data were because: 1) owners have the entire project perspective from planning to managing and controlling the project during the entire project development life cycle; 2) contractors' schedule dates for the planning and startup phases do not confirm whether they fully participated in the phases or not. Only industrial and typical projects were selected for inclusion in this analysis because industrial projects are presumably much more sensitive to time and cost since any types of delay on completion of these projects can potentially result in heavy losses for the owners. Non-typical projects were excluded since those are defined as "impacted by extraordinary factors that might influence performance or practice use metrics" in the questionnaire. Projects with a total project cost (TPC in a million dollars (MM)) between \$10 MM and \$500MM were selected because projects costing less than \$10MM or more than \$500MM may distort the analysis results. Each project's cost has been normalized to Chicago 2015, meaning that each project cost was adjusted by time and location. Projects in the data set include those that are grass roots, addition, or modernization in nature. Only projects having complete actual schedule dates across phases were selected for this research. Projects that reported any phases starting earlier than the planning phase were left out due to violation of the phase definition and any projects with reversed schedule dates, e.g., a phase's end date was before a start date, was removed. However, when possible such the case the baseline schedule is identical, the dates were corrected. After the selection process, a total of 355 projects remained in the data set and used for this research.

3.2.4 Descriptive Statistics of Project data

3.2.4.1 Project Characteristics

Among the 355 projects, 207 projects (58%) were classified as heavy industry, and 148 projects (42%) were light industry. Heavy industrial project in this research were classified as process projects or non-process projects. According to the taxonomy of Watermeyer (Watermeyer, 2002), where process projects were defined as “a classification of factory which transforms materials in bulk.” In detail, process projects include oil refining and chemical manufacturing and so on. Non-process projects include oil extraction, mining, and so forth. Among the 207 heavy industrial projects, 159 projects (77%) were from process projects, and 48 projects (23%) were non-process. In the remainder of the 148 projects, 120 projects (81%) were from pharmaceutical projects: 95 projects (64%) were pharmaceutical manufacturing, and 25 projects (17%) were pharmaceutical laboratories. The remaining 28 projects (19%) were other light industrial projects, such as automotive manufacturing and consumer products manufacturing. In terms of project size wise, 45% were $10MM-$50MM, followed by 33% at $100MM-$500MM and 23% were $50MM-$100MM. The collected projects were also classified by nature of each project. Modernization projects were the highest portion at 37%, followed by additions at 34% and grass roots at 28%. Location wise, 259 projects (73%) were built in the United States of America and Canada and 96 projects (27%) were built in overseas. Figure 3.3 shows further classifications of project size and nature by industry group. As shown in Figure 3.3, project size and nature were well distributed within the groups.

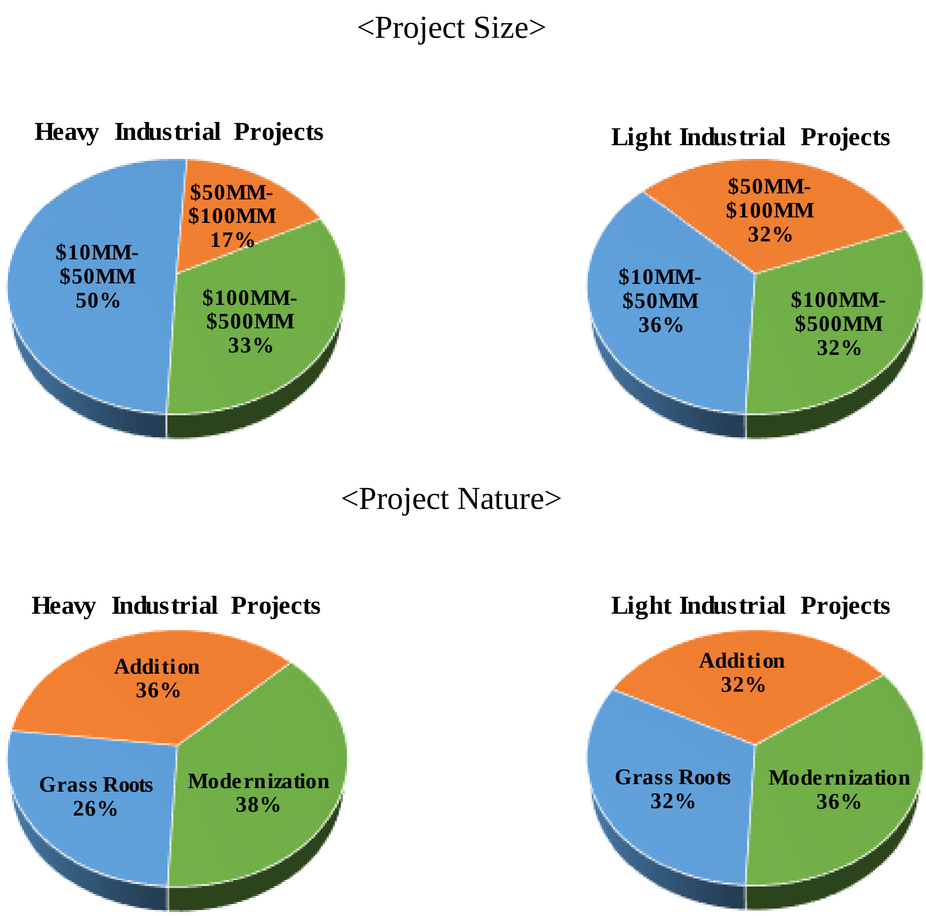


Figure 3.3 Data Distribution by Project Characteristics and Industry Group

Table 3.3 presents descriptive statistics of average TPC and duration of the projects used in the analysis. On average, projects cost $105.7 MM and spent 139.2 weeks in duration. Heavy industrial projects cost $103.7MM on average and were 143.7 weeks in duration. The figures were $108.5MM and 133 weeks for light industrial projects.

Table 3.3Descriptive statistics: Average TPC and Duration

	Project Type	All	\$10MM-\$50MM	\$50MM-\$100MM	\$100MM-\$500MM
Sample Size	All	355	158	81	116
	H.I.P*	207	104	34	69
	L.I.P**	148	54	47	47
Avg. \$TPC	All	\$105.7	\$25.6	\$71.2	\$238.9
	H.I.P	\$103.7	\$25.1	\$72.2	\$237.6
	L.I.P	\$108.5	\$26.5	\$70.4	\$240.9
Avg. Project Duration	All	139.2 weeks	114.7 weeks	136.1 weeks	174.7 weeks
	H.I.P	143.7 weeks	120.2 weeks	147.1 weeks	177.5 weeks
	L.I.P	133 weeks	104.3 weeks	128.2 weeks	170.8 weeks

*H.I.P stands for Heavy Industrial Projects
**L.I.P stands for Light Industrial Projects

3.2.4.2 Project Performance Outcomes

Table 3.4 summarizes the descriptive statistics for three metrics used to measure project's performance outcomes at the project level. Based on the means of the metric scores, projects in this research experienced 6.6% project schedule growth, -0.5% project cost growth, and 5.8% change cost factor. When the project size was considered as an influencing factor, no significant difference in the project schedule growth or the change cost factor was found with their corresponding p values of 0.278 and 0.867 respectively. On the other hand, project cost growth showed a significant difference (p=0.027) by the project size. When both the project size and the industry group were considered for measuring the project cost growth, only light industrial projects showed significant difference (p=0.006).

Table 3.4 Descriptive Statistics: Performance Outcomes

Performance		All			$10MM-$50MM			$50MM-$100MM			$100MM-$500MM		
		N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.
Project Schedule Growth	All	331	6.6%	18.3%	144	5.5%	17.4%	78	5.5%	12.2%	109	8.9%	22.5%
	H.I.P[1)]	193	5.9%	15.3%	95	5.4%	16.0%	33	4.4%	13.8%	65	7.5%	15.1%
	L.I.P[2)]	138	7.6%	21.7%	49	5.6%	19.9%	45	6.4%	11.0%	44	11.0%	30.3%
Project Cost Growth	All*	350	-0.5%	15.7%	158	-2.0%	16.1%	81	-2.1%	12.8%	111	2.8%	16.7%
	H.I.P	207	-1.0%	17.8%	104	-1.4%	18.1%	34	-5.3%	14.8%	69	1.7%	18.4%
	L.I.P*	143	0.2%	12.1%	54	-3.2%	11.3%	47	0.2%	10.7%	42	4.7%	13.5%
Change Cost Factor	All	290	5.8%	7.5%	134	5.7%	8.6%	69	5.6%	6.1%	87	6.2%	6.9%
	H.I.P	165	4.8%	7.6%	87	5.3%	9.5%	29	4.2%	4.9%	49	4.2%	4.5%
	L.I.P	125	7.2%	7.2%	47	6.3%	6.6%	40	6.7%	6.6%	38	8.7%	8.4%

[1)] H.I.P stands for Heavy Industrial Projects

[2)] L.I.P stands for Light Industrial Projects

*and yellow colored cell indicate statistically significant at $\alpha < 0.05$

3.3 Data Analysis Procedure and Methods

The objectives of this research are to characterize the phase arrangements used by industrial capital projects and to examine quantitatively the impact of the phase arrangements on duration and project performance outcomes. To fulfill these objectives, appropriate procedures and methods have been selected and utilized. This section describes the procedure that provides the backbone of the data analyses and corresponding methods in each step of the procedure.

3.3.1 Phase Arrangement in the Project Development Life Cycle

This section describes the procedures and methods for answering research question 1. The research question characterizes project development life cycle phase arrangement and quantifies the arrangement by various project characteristics. Phase arrangement is defined as the relative position and sequence of the phases. To examine this, phase starting time and duration for each of the five phases of all collected projects needed to be normalized first for data preprocessing. The duration was calculated from the difference between the normalized phase end and start times. Once the data preprocessing was completed, the next step was to test whether various project characteristics influence those variables significantly. That is to say, it determine if the phase start time and duration of each phase were significantly changed by the project characteristics. Figure 3.4 illustrates the procedure for research question 1 along with a list of which project characteristics were utilized. As shown in the figure, four project characteristics were considered: industry group, project type, project nature, and project size in order. The last step was to develop graphical illustration to see how the five phases are arranged by deploying a series of box-and-whisker' plots with consideration of the determinants that made impactful change.

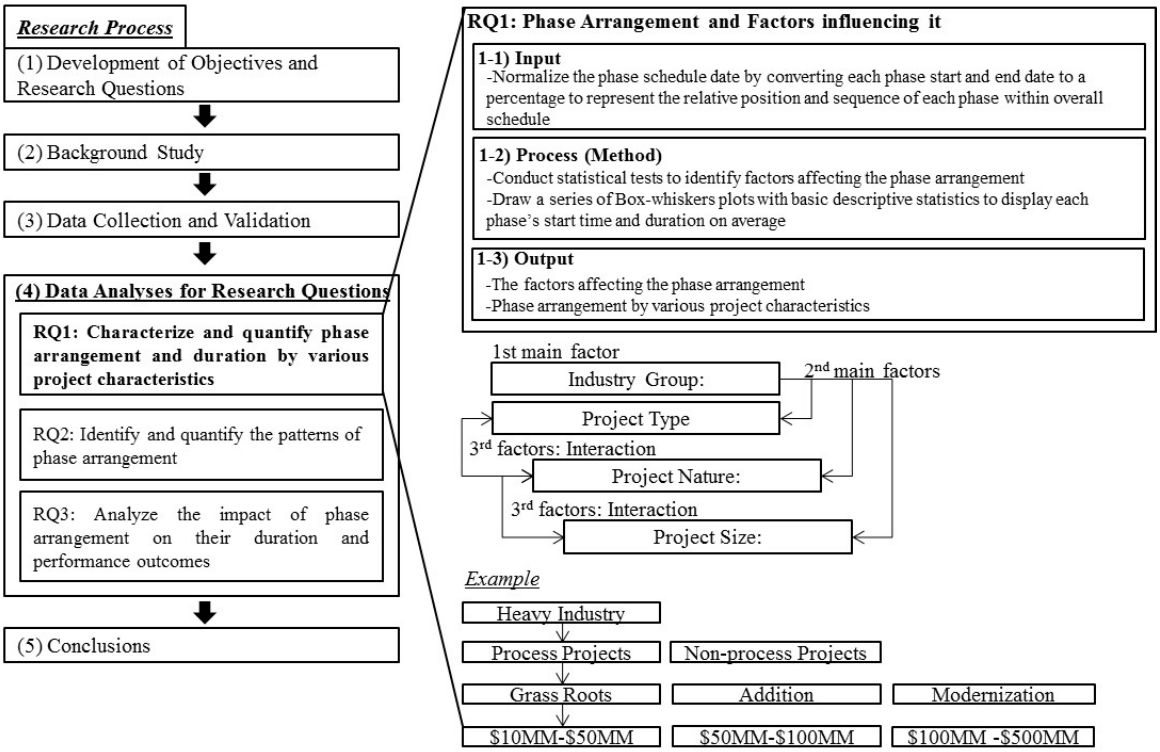


Figure 3.4 Conceptual Process for Research Question 1

3.3.1.1 Data Preprocessing for Quantification

As stated in the previous section, the start and end dates of a phase for all collected projects were normalized since every project was initiated and built in various times and duration for each phase. The normalization process included conversion of a specific date to a percent value by Equation (1). For example, if there was a project started on May 27th 2012 and completed on February 3rd, 2013 with a certain phase start time (x) on June 5th, 2012, the normalized date for x would be represented as 3.6 percent, meaning that the phase was started when a project reached 3.6 percent completion based on overall duration.

$$Date\ conversion\ for\ (x) = \frac{(the\ phase\ start\ time\ x - \text{project's}\ earliest\ start\ time\ )}{(\text{project's}\ latest\ end\ time - \text{project's}\ earliest\ start\ time)} \times 100 \qquad (1)$$

3.3.1.2 Influencing Factors on Phase Arrangement

One of the primary objectives of research question 1 is to find key determinants (factors) influencing phase arrangement in the project development life cycle. This is done not only to illustrate how the phase start time and duration were affected by various project characteristics but also to help ascertain the typical phase arrangement employed in the project development life cycle. The phase arrangement for research question 1 illustrates the five phases' relative sequence and position in the overall project schedule. To represent a phase's sequence and position, each phase's start time and duration are required. In addition, to identify factors affecting the phase arrangement, those two variables, normalized, need to be used as dependent variables.

The key factors used for research question 1 can be classified as exogenous factors. This means that the factors have been decided before the planning of a project was initiated such as industrial group, project type, nature, and size in $MM. As stated in the process (refer to Figure 3.4), industry group is considered as the first main factor with the assumption that the dependent variables (average phase's start time and duration) in heavy industrial projects were significantly different from those in light industrial projects. Once the assumption is determined to be true, the data set will be divided to represent each industrial group. In each industrial group, whether or not the remaining factors influence the changes of means (or medians) for the dependent variables are tested.

In general, research question 1 is to determine whether two or more groups' dependent variables are different from each other or amongst others under a certain project characteristics. In this case, the statistical method can be the independent sample t-test (t-test) or Analysis of Variance (ANOVA). However, depending on the data's normality, a non-parametric such as Mann-Whitney *U* test or Kruskal-Wallis H test can be necessary. For example, Kruskal-Wallis H test determines whether the medians of two or more groups are different. If data fit for normality, t-test or ANOVA needs to be selected as a statistical method to test whether a chosen factor affect the dependent variables with two tailed at $p \leq 0.05$. A two-tailed test was selected since the underlying hypothesis was that the variables were not equal amongst project characteristics. However, if the homogeneity of variance assumption among others is violated, the welche's t-test is used instead. Post hoc tests are necessarily followed to see which specific group of data is different from others.

3.3.1.3 Characterization of Phase Arrangement in the Project Development Life Cycle

Phase arrangement is the combination of various components of phases. At a micro level it includes a phase's start and end times with its duration, whereas, at a macro level, it illustrates how the five phases in the project development life cycle are arranged. It also shows the extent of concurrency among the five phases and provides the basis for comparison amongst other phase arrangements with different project characteristics.

Figure 3.5 provides a graphic that illustrates how to read the components of the engineering phase in the phase arrangement. The example was constructed with the extracted data set that contains the mean start and end times of the engineering phase for all industrial projects. The mean start and end times appear on the x-axis which shows the percentage value in overall schedule, where 0 (zero) indicates a project initiated, and 100% indicates a project completed. The box- and-whisker plot on top of the figure describes the variation of the start time, whereas the box-and-whisker plot at the bottom represents the variation of the end time. Further, the illustration indicates the mean values of the engineering start time and end time, 0.265 (26.5% in the overall schedule) and 0.656 (65.6%) respectively. From this information, it is simple to infer that the duration of the engineering phase in industrial projects, on average, is 0.391 (39.1%). The variation of the engineering phase start time fell between 0% and 61.4%, and the variation of the engineering phase end time fell between 18.2% and 100%. The light-red colored box in the middle of Figure 3.5 with its duration is the engineering phase that will be used for phase arrangement in the project development life cycle.

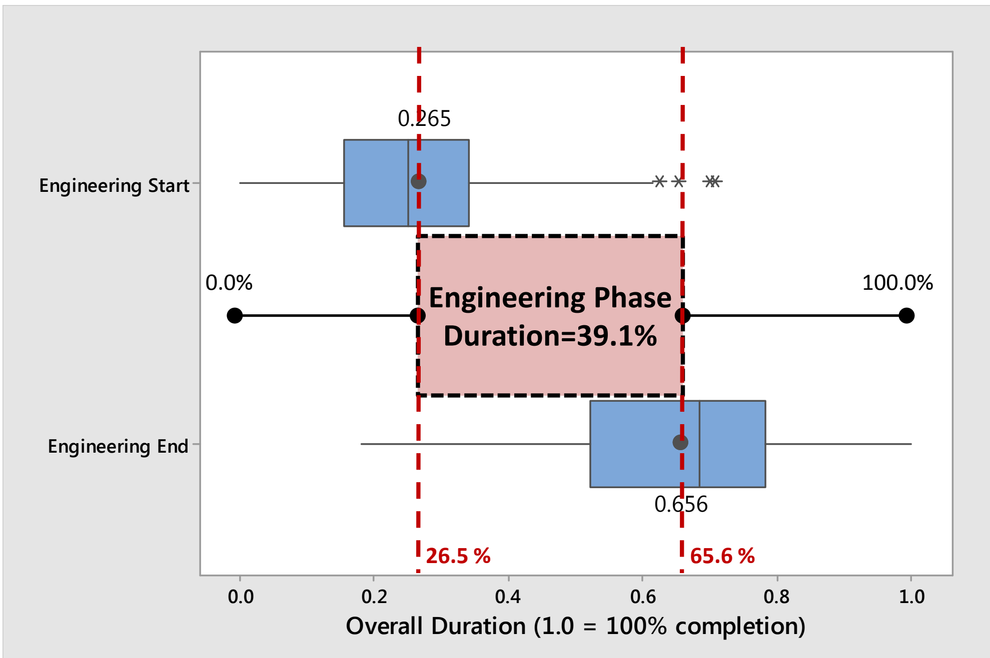


Figure 3.5 An Illustration of How-to-Read Phase Components in the Phase Arrangements

Figure 3.6 depicts the percent completion of A phase prior to starting of B phase. Duration of phase A is 10 weeks, and duration of phase B is 12 weeks. The difference in start time between A and B is 2 weeks meaning that B is started 2 weeks later than A starts. The given phase arrangement, the percent completion equals to 20% based on provided formula (2). This means that phase B started with 20% completion of phase A.

$$Percent\ Completion = \frac{\text{Difference in start time of the two phases}}{\text{Duration of Predecessor phase}} \times 100 \qquad (2)$$

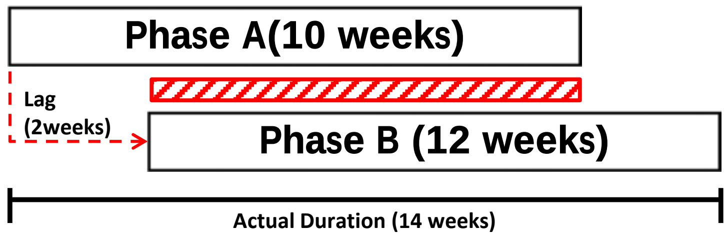


Figure 3.6 An Illustration of How to Calculate the Percent Completion

3.3.2 Patterns of Pairwise and Triple-wise Phase Arrangements

The previous section describes 1) how the project schedule date is quantified, 2) which elements are used for characterizing the typical phase arrangement in the project development life cycle, and 3) how to construct the phase arrangement employed in the industrial capital projects. In this section, the means by which patterns for two phases in the project development life cycle are identified is presented. The phase arrangements share the same components as used in the analysis of phase arrangement in the project development life cycle: start time, end time, and duration. However, the arrangements of the two (or three) phases are squared focusing on the detailed level of phase sequences. Figure 3.7 describes the process to identify the patterns of phase arrangements for two phases. The first step is to setup a conceptual phase arrangement with consideration of phase start and end dates. There can be three types of arrangements in a broad sense: sequential, parallel, and reversed sequential. Reversed sequential indicates that a certain phase starts earlier than its typically preceding phase. For example, the procurement phase typically follows the engineering phase, but a reversed sequential order would have the procurement phase starts earlier than the engineering phase start. The next step is to quantify the frequencies of each pattern found in the project development life cycle data. The output is similar to the format shown in Figure 3.7, which consists of the actual number found for a pattern and its percentage of the sample size. As an output, common patterns across industry group or other project characteristics are identified. At the same time, rare but existing patterns are recognized as well. Once all the steps for two-phased patterns are completed, the arrangements for three phases will be examined based on the results of the patterns identified in the previous step. The three phased patterns are the combinations of existing patterns found for two phases.

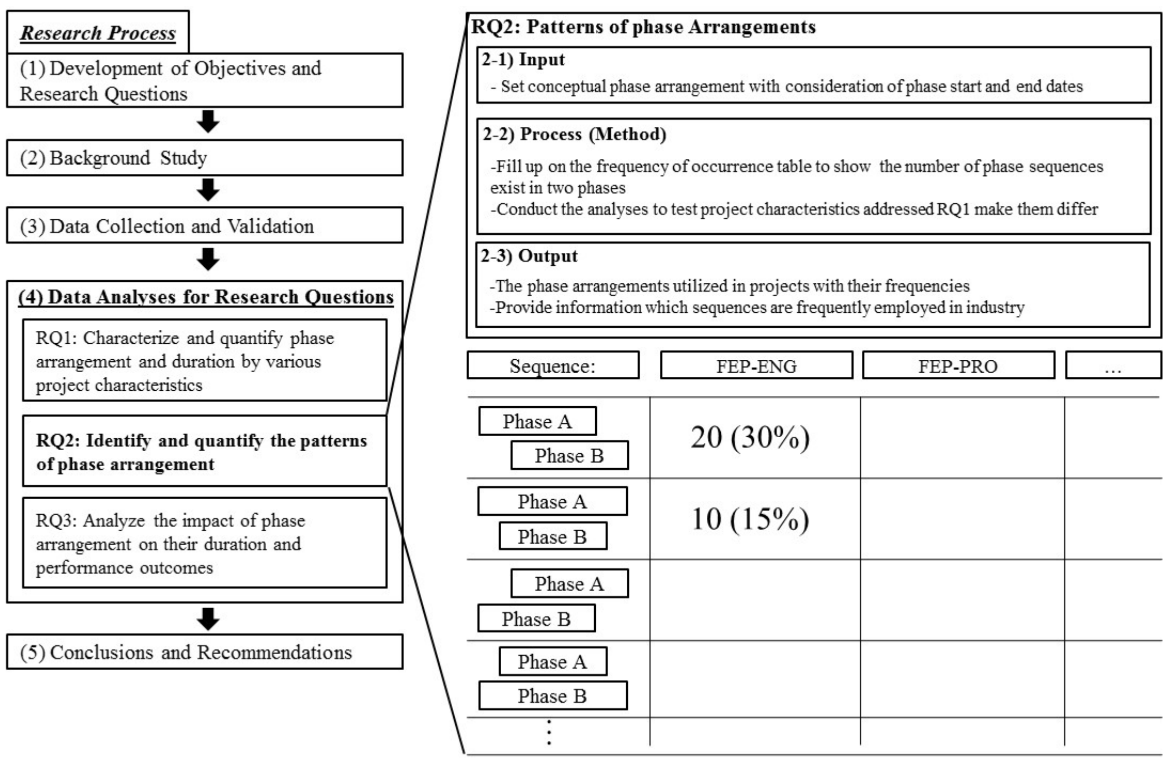


Figure 3.7 Conceptual Process for Research Question 2

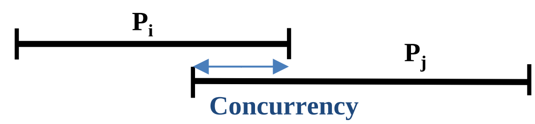
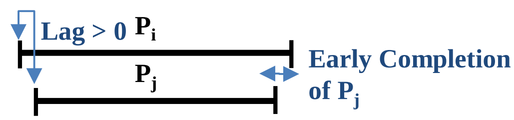
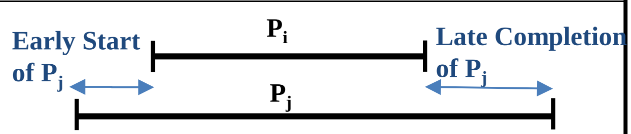
3.3.2.1 Identification of Phase Arrangements

Some researchers have worked to characterize activity relationships (Bogus et al., 2006; Peña-Mora & Li, 2001; Prasad, 1996). Their contribution was limited to the relationship of the activities in a sequential manner, however. Furthermore, the four typical relationships between two activities, start to start, start to finish, finish to finish, and finish to start in the critical path method are not sufficient to identify the relationships at the phase level as in the PEpC model, where two partitioned phases (two separate procurement phases) exist with distinct objectives. The main reason is that at the phase level, it is hard to define how the phases link to each other exactly since all phases are inter-related. In addition, the sequences and start times of the phases are presumably the results of a strategic decision from the project's stakeholders.

In the conventional development process, where all five phases are consistent with the finish to start relationship, the relationship between phases can be easily characterized. However, allowing a certain extent of concurrency between phases makes it hard to define the relationships since the succeeding phase starts while the preceding phase is still progressing. As an alternative, a structural pattern can be used for identification of patterns employed in industrial capital projects. According to Witten (2011), "the structural pattern can be examined, reasoned about, and used to inform future decision."

At the phase level, the sequences of phases can be structured to a sequential, parallel, or reversed sequential sequence. The sequential sequence is the one typically defined as the finish to start relationship with a certain level of concurrency, where the level can be started from zero. The primary constraint is that the succeeding phases should be completed after the preceding phase is completed. The parallel sequence is one in which the phases are performed in parallel most of their time, and either of the phases' duration is absorbed to the counterpart which means that the phase with absorbed duration does not contribute to the increase or decrease of the overall duration. Table 3.5 illustrates the patterns conceptually recognized with the three sequences.

Table 3.5 Patterns and their graphical illustration

<table>
<tr><td>Pattern Description</td><td>Phase Arrangement Patterns includes:
(P_i : the preceding phase and P_j: the succeeding phase)</td></tr>
<tr><td>Sequential arrangement of two phases</td><td>
</td></tr>
<tr><td>Parallel arrangement of two phases</td><td>
</td></tr>
<tr><td>Reversed sequential arrangement of two phases</td><td>
</td></tr>
</table>

The pair wise phase arrangements are constructed based on the consideration of phases' start times, end times, and durations. The triple wise phase arrangements are the combination of the identified patterns of the two phases and focused on three adjacent phases, i.e., the planning, engineering, and procurement phases. The actual phases' combination are as follows: 1) FEP: the Front-end planning-Engineering-Procurement phases, 2) EPC: the Engineering-Procurement-Construction phases, and 3) PCS: the Procurement-Construction-Startup phases. The reason for these selections is that these three combinations are believed to the core phases that require contractor's involvement, which, in turn, means that they are the most beneficial for owners to understand the impact of phase arrangements on duration and performance outcomes.

3.3.3 Impact Analysis of Pairwise and Triple-wise Phase Arrangements on Duration and Performance Outcomes

This section describes the procedures and methods for answering research question 3. The purpose of the research question is to test whether the identified phase arrangement patterns influence duration or project performance outcomes. Figure 3.8 illustrates the procedure that shows how the test is conducted with inputs and expected outputs. The inputs, i.e., identified phase arrangement patterns are chosen as independent variables (IVs) and corresponding durations (or performance outcomes) are selected as dependent variables (DVs). To test differences on the DVs by IVs, a statistical test is performed under a certain condition. The condition is represented by various project characteristics, and those characteristics classify projects into groups for data analysis.

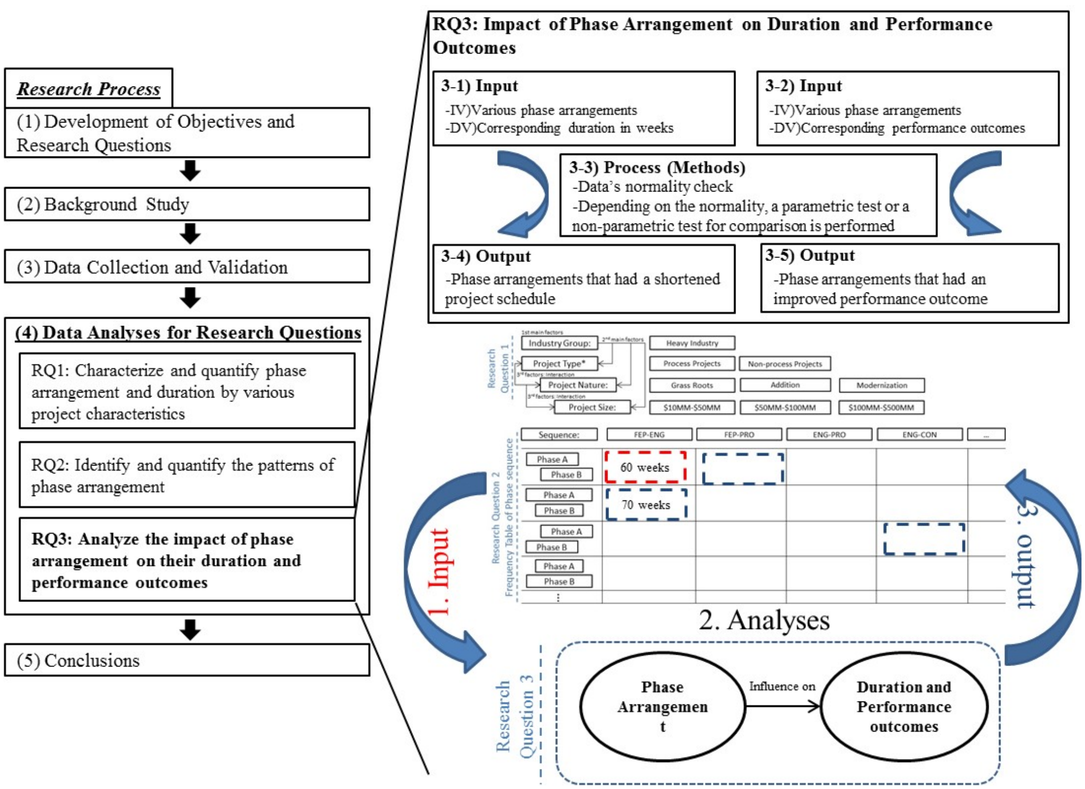


Figure 3.8 Conceptual Process for Research Question 3

When the durations of phase arrangements are tested, the focal point of the analysis is to find which phase arrangement had a shortened or lengthened duration. For performance outcomes, finding which phase arrangement had an improved performance is the point of interest. The selection of an appropriate method is essential to test the statistically significant difference between two or more groups. For research question 3, the choice for comparison analysis is between a parametric test (i.e., independent sample t-test: t test) and a non-parametric test (i.e, Mann-Whitney U test: MWU). The distinctive difference between them is whether the data for comparison fits for normality (Minchin et al., 2013; O'Connor & Yang, 2004). Green et al (2000) suggested the following guidelines for selection between the t-test and MWU: 1) if the data fit for normality, a t-test is preferred; 2) if the population distributions are symmetrical and flat, either test can be selected; 3) if the distributions are symmetrical but with thicker tail than a normal distribution or non-normal, a MWU test is selected. In addition, before analyzing data for comparison in the selected phase combinations, extreme outliers are removed from each phase arrangement pattern by using 3 times IQR (interquartile range) as shown in Figure 3.9. Moreover, there are several ways to check data's normality graphically: histogram, boxplot, P-P plot (Probability-Probability plot), and Q-Q plot (Quantile-Quantile plot) to list a few (Ghasemi & Zahediasl, 2012). However, those tests are supplementary to the graphical assessment. Therefore, this research selected the Shapiro-Wilk test to check normality since it supplies better power than the Kolmogorov-Smirnov (K-S) test (Ghasemi & Zahediasl, 2012).

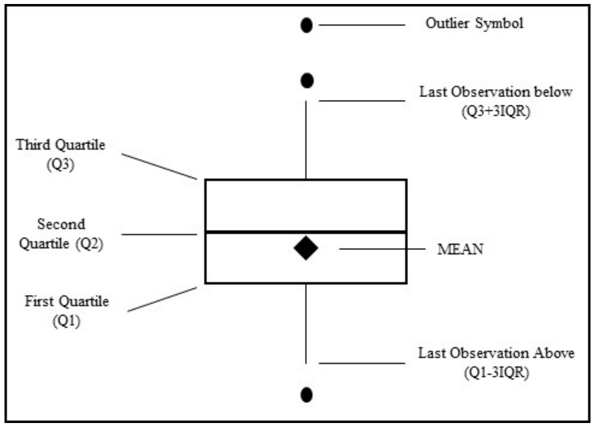


Figure 3.9 Sample Box and Whisker Diagram

Two types of durations were tested: combined and overall. The combined duration indicates the sum of the durations of each phase used in a phase arrangement. The overall duration is the duration of the phase arrangement and is calculated from the latest phase's end time minus the earliest phase's start time. The two types of duration factors correspond to the two types of durations that are used to measure a relative duration of phase arrangement over combined durations of all phases or overall duration of all phases. The purpose of comparison for the combined duration is to measure whether a difference in duration exists regardless of the effect of various phase arrangements on duration. On the other hand, the comparison of the overall duration measures whether difference in duration exists with respect to the effect of various phase arrangements on duration.

Five performance outcomes were tested: schedule growth of phase arrangement, cost growth of phase arrangement, project schedule growth, project cost growth, and project change cost factor. Schedule growth or cost growth of a phase arrangement is intended to measure the schedule or cost deviation from the original planned by various phase arrangements with specific focuses on phases that belong to the phase arrangement. For example, If actual duration of PA is 65 weeks and initial duration of PA is 100 weeks, then the schedule growth of phase arrangement is -35% (-35% = (65-100)/100*100). Table 3.6 presents the definition of performance metric used for research question 3.

Table 3.6 Definition of Performance Metric used for Research Question 3

<table>
<tr><th colspan="2">Performance Metric</th><th>Metric Definition</th></tr>
<tr><td rowspan="2">Schedule</td><td>Project Schedule Growth</td><td><u>Actual Total Project Duration - Initial Predicted Project Duration</u>
Initial Predicted Project Duration</td></tr>
<tr><td>Schedule Growth of Phase Arrangement</td><td><u>Actual Duration of PA – Initial Predicted Duration of PA</u>
Initial Predicted Duration of PA
PA: Phase Arrangement</td></tr>
<tr><td rowspan="2">Cost</td><td>Project Cost Growth</td><td><u>Actual Total Project Cost - Initial Predicted Project Cost</u>
Initial Predicted Project Cost</td></tr>
<tr><td>Cost Growth of Phase Arrangement</td><td><u>Actual Cost of PA – Initial Predicted Cost of PA</u>
Initial Predicted Cost of PA
PA: Phase Arrangement</td></tr>
<tr><td>Change</td><td>Change Cost Factor</td><td><u>Total Cost of Changes</u>
Actual Total Project Cost</td></tr>
</table>

Furthermore, there are myriad factors affecting duration and performance outcomes. For duration, factors include utilizing schedule reduction techniques, implementing schedule compression techniques, change order, or rework, to list a few. For performance, whether best practices were implemented can improve or decrease effectiveness, for example. Either quality of planning or engineering may affect the construction duration or performance. Since there are so many factors it is not possible to isolate any one cause from the data, therefore, this research assumes no effects from other factors on duration and performance outcomes exist.

CHAPTER 4: CHARACTERIZATION OF PHASE ARRANGEMENT IN THE PROJECT DEVELOPMENT LIFE CYCLE

4.1 INTRODUCTION

This chapter describes research results found regarding the phase arrangements in the project development life cycle. Phases can be illustrated graphically to show how the five phases were arranged in the project development life cycle and to highlight their relative positions, sequences, and duration. To do so, quantification of each phase's start time and duration of the collected projects was essential input to characterize the phase arrangement. Since all the projects were built at various times and had different durations, normalization was performed. External factors (project characteristics) that influence the variables (phase start time and duration) were also captured to allow for further classification. The underlying hypothesis for research question 1 is that there are certain project characteristics that significantly affect phase start time or duration. Industry group, project type, nature, and size are considered to be project characteristics. Multiple statistical tests were performed to confirm which project characteristics affected the variables significantly. Mean and standard deviation (S.D) values in the result table in the following sections are bold and underlined when the group's data fits for normality and the test results are statistically significant by the t-test (ANOVA). If the median is bold and underlined, then the groups' data did not fit for normality, but the test result is statistically significant by the MWU (Krukal-Wallis H) test. If a group's sample size is less than 20, the group is not presented.

4.2 IDENTIFICATION OF FACTORS INFLUENCING PHASE'S START TIME

Tables 4.1 and 4.2 presents the sample results of normality test for phase start time and duration. As shown in the tables, some categories of project characteristics did not follow the normal distribution. Based on the results of the normality test, either the t-test (or ANOVA) or MWU (or Kruskal-Wallis H test) was selected. Additional results of normality are attached in Appendix B.

Table 4.1 Normality Test Results for Phase Start Time of Process Projects by Nature

Category		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Detailed Engineering	Grass roots	0.128	38	0.121	0.979	38	0.683
	Addition	0.095	54	.200*	0.967	54	0.145
	Modernization	0.060	67	.200*	0.990	67	0.875
Procurement	Grass roots	0.116	38	.200*	0.928	38	0.018
	Addition	0.071	54	.200*	0.981	54	0.552
	Modernization	0.116	67	0.026	0.974	67	0.165
Construction	Grass roots	0.070	38	.200*	0.986	38	0.918
	Addition	0.084	54	.200*	0.967	54	0.142
	Modernization	0.064	67	.200*	0.990	67	0.870
Startup	Grass roots	0.144	38	0.045	0.899	38	0.002
	Addition	0.245	54	0.000	0.746	54	0.000
	Modernization	0.230	67	0.000	0.753	67	0.000

Shaded cells indicate non normal distribution of data within category.

Table 4.2 Normality Test Results for Phase Duration of Process Projects by Nature

Category		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Front-End Planning	Grass roots	0.095	38	.200*	0.973	38	0.493
	Addition	0.099	54	.200*	0.969	54	0.179
	Modernization	0.097	67	0.194	0.972	67	0.127
Detailed Engineering	Grass roots	0.142	38	0.051	0.892	38	0.002
	Addition	0.083	54	.200*	0.980	54	0.512
	Modernization	0.083	67	.200*	0.977	67	0.249
Procurement	Grass roots	0.067	38	.200*	0.992	38	0.995
	Addition	0.064	54	.200*	0.991	54	0.960
	Modernization	0.094	67	.200*	0.982	67	0.442
Construction	Grass roots	0.063	38	.200*	0.988	38	0.949
	Addition	0.124	54	0.037	0.938	54	0.008
	Modernization	0.069	67	.200*	0.988	67	0.768
Startup	Grass roots	0.147	38	0.037	0.890	38	0.001
	Addition	0.230	54	0.000	0.725	54	0.000
	Modernization	0.268	67	0.000	0.656	67	0.000

Shaded cells indicate non normal distribution of data within category.

4.2.1 Industrial Projects

Table 4.3 presents the percent mean of phase start time by the given categories of project characteristics, along with its standard deviation and median. The front-end planning phase was not included in this analysis since all projects' values are zero, by definition. The results indicate that median start time for all subsequent phases differed by industry group significantly at $p < 0.05$, meaning that industry group is a major factor differentiating phase start time. In other words, phases in heavy industrial projects started later than those phases in light industrial projects. For example, detailed engineering of heavy industrial projects started later, with a median value of 29.6% than light industrial projects at 18.5%, and this difference was statistically significant by the MWU test at $p<0.05$ ($U = 8957.5$, $z = -6.672$, $p=0.000 <0.05$). Construction of heavy industrial projects started later, with a median value of 52.9% than light industrial projects at 35.1%, and the difference was statistically significant at $p<0.05$ ($U = 7608$, $z = -8.087$, $p = 0.000 < 0.05$).

Project type was found to affect only the detailed engineering phase start time in heavy industrial projects, meaning that detailed engineering of process projects started later, with a mean of 31.7% than detailed engineering of non-process projects at 26.3%. The difference in mean values was statistically significant at $p<0.05$ ($F(1,205) = 5.607$, $p = 0.019 < 0.05$). The procurement and startup phases were affected by project type in light industrial projects. Specifically, a Kruskal-Wallis H test showed that there was a statistically significant difference in start time of procurement amongst projects with various project types in light industrial projects (X^2 (2) = 7.945, $p = 0.019 < 0.05$). In addition, start time of startup amongst projects with various project types in light industrial projects had a statistically significant difference by a Kruskal-Wallis H test (X^2 (2) = 9.750, $p = 0.008 < 0.05$).

In terms of project type, all phases of non-process projects started earlier than process projects on average. In light industrial projects, the phases of pharmaceutical manufacturing started earlier on average than other project types, except in the case of the engineering phase. Interestingly, the procurement phase started right after the engineering phase with an average 1.5%p difference in heavy industrial projects and a 3.2%p difference on average in light industrial projects.

Table 4.3 Phase's Start Time in Percent Value for Industrial Projects

Category (Standard Deviation: S.D.)		Sample Size	Phases of the Project Development Life Cycle			
			Detailed Engineering	Procurement	Construction	Startup
Industry Group	Mean	355	26.5%	28.7%	46.7%	85.1%
	S.D.		14.1%	16.5%	18.0%	14.1%
	Median		**25.1%**	**27.6%**	**45.3%**	**88.8%**
Heavy Industrial Projects	Mean	207	**30.4%**	31.9%	53.1%	91.3%
	S.D.		**13.8%**	16.3%	17.0%	10.0%
	Median		29.6%	31.7%	52.9%	95.0%
o Process Projects	Mean	159	31.7%	32.2%	53.2%	91.6%
	S.D.		14.0%	17.1%	16.2%	9.9%
	Median		30.0%	31.7%	53.2%	95.7%
o Non-process Projects	Mean	48	26.3%	30.7%	52.8%	90.4%
	S.D.		12.6%	13.4%	19.5%	10.3%
	Median		26.8%	31.6%	51.9%	93.7%
Light Industrial Projects	Mean	148	21.0%	24.2%	37.8%	76.4%
	S.D.		12.6%	15.8%	15.4%	14.4%
	Median		18.5%	**21.0%**	35.1%	**78.6%**
o Pharmaceutical Manufacturing	Mean	95	21.0%	21.5%	36.4%	73.8%
	S.D.		11.8%	14.0%	14.8%	14.7%
	Median		19.7%	18.9%	33.4%	74.5%
o Pharmaceutical Laboratory	Mean	25	19.5%	31.1%	39.2%	81.9%
	S.D.		12.1%	15.4%	11.8%	9.5%
	Median		16.8%	27.3%	37.2%	81.2%
o Other Light Industrial Projects	Mean	28	22.3%	27.4%	41.0%	80.5%
	S.D.		15.4%	19.5%	19.4%	15.1%
	Median		18.3%	25.4%	35.7%	84.0%

Bold in underline indicates a group that is statistically significant (p<0.05).

4.2.2 Heavy Industrial Projects

Table 4.4 presents the percent mean phase start time for heavy industrial projects, along with their standard deviation and median. This demonstrates how each phase's percent mean or median value differed across various project characteristics including project nature and project size. Again, the front-end planning phase was removed.

Results indicate that the construction phase's start time in mean differed according to project nature, with modernization projects (58%) starting significantly later than grass roots (48%) and addition projects (50.9%) at the $p<0.05$ by ANOVA ($F(2,156) = 5.763$, $p = 0.004 < 0.05$). This means that project nature affects start time of construction. It was also observed that the median startup phase's start time differed according to project nature, with modernization projects (97.6%) starting significantly later than grass roots projects (92.8%). The difference was statistically significant by the Kruskal-Wallis H test (X^2 (2) = 9.965, $p = 0.007 < 0.05$). For project size, the construction phase's median start time differed with projects costing \$10MM-\$50MM starting later (60%) than projects costing \$100MM-\$500MM (49.5%). The difference in median was statistically significant by a Kruskal-Wallis H test (X^2 (2) = 10.952, $p = 0.004 < 0.05$).

Although there was no statistical difference found, it was observed that modernization projects tended to start later across all phases. In addition, as the project size increased, the phase start times become faster. The interesting point is that as the project size increased, there is a tendency for the procurement phase to start earlier than the start of the engineering phase. Statistical comparison of the categories of project characteristics for non-process projects was not conducted due to small sample size.

Table 4.4 Phase's Start Time in Percent Value for Heavy Industrial Projects

Category (Standard Deviation: S.D.)		Sample Size	Phases of the Project Development Life Cycle			
			Detailed Engineering	Procurement	Construction	Startup
Process Projects	Mean	159	31.7%	32.2%	53.2%	91.6%
	S.D.		14.0%	17.1%	16.2%	9.9%
	Median		30.0%	31.7%	53.2%	95.7%
o Project Nature	Mean	159	31.7%	32.2%	**<u>53.2%</u>**	91.6%
	S.D.		14.0%	17.1%	**<u>16.2%</u>**	9.9%
	Median		30.0%	31.7%	<u>53.2%</u>	**<u>95.7%</u>**
Grass Roots	Mean	38	30.6%	30.5%	48.0%	90.4%
	S.D.		12.6%	18.5%	12.0%	7.7%
	Median		28.8%	31.3%	47.7%	92.8%
Addition	Mean	54	30.4%	31.5%	50.9%	90.7%
	S.D.		15.9%	16.5%	17.6%	11.6%
	Median		30.4%	32.0%	51.5%	95.9%
Modernization	Mean	67	33.3%	33.9%	58.0%	92.9%
	S.D.		13.1%	16.9%	16.0%	9.6%
	Median		33.0%	30.0%	60.2%	97.6%
o Project Size	Mean	159	31.7%	32.2%	53.2%	91.6%
	S.D.		14.0%	17.1%	16.2%	9.9%
	Median		30.0%	31.7%	**<u>53.2%</u>**	95.7%
$10MM-$50MM	Mean	86	32.1%	34.6%	56.4%	93.2%
	S.D.		15.3%	16.2%	17.4%	8.4%
	Median		31.2%	34.3%	60.0%	96.0%
$50MM-100MM	Mean	26	32.0%	30.5%	50.6%	89.5%
	S.D.		14.7%	20.3%	16.2%	12.2%
	Median		32.9%	26.6%	50.6%	96.1%
$100MM-$500MM	Mean	47	30.6%	29.0%	48.7%	89.8%
	S.D.		10.9%	16.5%	12.6%	10.8%
	Median		28.7%	28.2%	49.5%	93.2%
Non-process Projects	Mean	48	26.3%	30.7%	52.8%	90.4%
	S.D.		12.6%	13.4%	19.5%	10.3%
	Median		26.8%	31.6%	51.9%	93.7%
o Project Nature Addition	Mean	20	27.2%	33.3%	46.3%	87.2%
	S.D.		13.7%	13.1%	15.1%	10.2%
	Median		26.4%	33.7%	48.7%	90.0%
o Project Size $100MM-$500MM	Mean	22	25.7%	28.3%	48.0%	88.8%
	S.D.		12.3%	14.6%	12.2%	11.0%
	Median		27.9%	25.8%	48.1%	91.8%

Bold in underline indicates a group that is statistically significant ($p<0.05$).

4.2.3 Light Industrial Projects

Table 4.5 presents the percent mean of phase start time for light industrial projects, along with their standard deviation and median. Comparison by various project characteristics including project nature and project size were analyzed. Again, the front-end planning phase was not included since all projects' value are zero in this phase. Due to small sample size ($N<20$), statistical comparisons for pharmaceutical laboratories and other light industrial projects were not conducted.

Analysis results showed that construction phase start time differs by project nature for pharmaceutical manufacturing projects, with grass roots projects starting (31.2%in mean) earlier than addition (39.9%) and modernization projects (38.7); and the difference amongst groups is statistically significant at $p<0.05$ by ANOVA test ($F(2,92) = 3.378$, $p = 0.038 < 0.05$). Phase start times were not found to differ by project size. Although no statistical difference was found, it was observed that addition projects tended to start later on all phases on average. Furthermore, as the project size increased in pharmaceutical manufacturing projects, the phase start times, on average, were earlier, except for the engineering phase.

Table 4.5 Phase's Start Time in Percent Value for Light Industrial Projects

Category (Standard Deviation: S.D.)		Sample Size	Phases of the Project Development Life Cycle			
			Detailed Engineering	Procurement	Construction	Startup
Pharmaceutical Manufacturing	Mean	95	21.0%	21.5%	36.4%	73.8%
	S.D.		11.8%	14.0%	14.8%	14.7%
	Median		19.7%	18.9%	33.4%	74.5%
o Project Nature	Mean	95	31.7%	32.2%	**<u>53.2%</u>**	91.6%
	S.D.		11.8%	14.0%	**<u>14.8%</u>**	14.7%
	Median		19.7%	18.9%	33.4%	74.5%
Grass Roots	Mean	33	20.2%	21.4%	31.2%	72.3%
	S.D.		11.0%	13.7%	12.8%	14.4%
	Median		18.7%	18.0%	30.4%	74.5%
Addition	Mean	27	22.3%	24.5%	39.9%	79.9%
	S.D.		11.8%	13.3%	14.3%	12.0%
	Median		20.9%	28.1%	42.5%	81.6%
Modernization	Mean	35	20.9%	19.2%	38.7%	70.5%
	S.D.		12.9%	14.8%	15.9%	15.7%
	Median		19.2%	13.7%	34.2%	70.8%
o Project Size	Mean	95	31.7%	32.2%	53.2%	91.6%
	S.D.		11.8%	14.0%	14.8%	14.7%
	Median		19.7%	18.9%	33.4%	74.5%
$10MM-$50MM	Mean	29	23.3%	24.1%	41.3%	75.9%
	S.D.		13.6%	14.5%	14.5%	15.5%
	Median		21.0%	20.1%	39.6%	78.1%
$50MM-100MM	Mean	30	19.8%	21.0%	35.3%	74.1%
	S.D.		12.4%	15.3%	13.8%	15.3%
	Median		15.2%	16.0%	32.8%	77.0%
$100MM-500MM	Mean	36	20.3%	19.7%	33.5%	71.9%
	S.D.		9.8%	12.5%	15.3%	13.5%
	Median		19.7%	20.2%	32.5%	71.9%
Pharmaceutical Laboratory	Mean	25	19.5%	31.1%	39.2%	81.9%
	S.D.		12.1%	15.4%	11.8%	9.5%
	Median		16.8%	27.3%	37.2%	81.2%
Other Light Industrial Projects	Mean	28	22.3%	27.4%	41.0%	80.5%
	S.D.		15.4%	19.5%	19.4%	15.1%
	Median		18.3%	25.4%	35.7%	84.0%

Bold in underline indicates a group that is statistically significant ($p<0.05$).

4.3 IDENTIFICATION OF FACTORS INFLUENCING PHASE'S DURATION

4.3.1 Industrial Projects

The following sections present analysis results for phase duration by different industry groups. Table 4.6 presents the percent mean phase duration by industry group, along with their standard deviation and median. The table demonstrates how percent mean or median values differ according to various project characteristics including industry group and project types.

Analysis results indicate that all phase durations except the procurement phase differed by industry group significantly at $p<0.05$, meaning that industry group is a major factor that differentiates phase duration. In detail, duration of construction in heavy industrial projects (42.3% in mean) tended to be shorter than in light industrial projects (53.2% in mean), and the difference in mean was statistically significant at $p<0.05$ by t-test (t (353) = -6.268, p = 0.000 < 0.05). Front-end planning in heavy industrial projects (29.2% in median) had longer duration than the front-end planning in light industrial projects (21.4% in median), and the difference was statistically significant at $p<0.05$ by MWU test (U = 10367.5, z = -5.193, p = 0.000 < 0.05). Similarly, detailed engineering in heavy industrial projects had longer duration with 41.1% median than light industrial projects that had a median of 30.8%, and the difference was statistically significant at $p<0.05$ (U = 10641, z = -4.906, p = 0.000 < 0.05). On the other hand, the startup in heavy industrial projects had shorter duration (4.1%) than the startup in light industrial projects (20.2%), and the difference in median was statistically significant at $p<0.05$ (U = 4951, z = -10.875, p = 0.000 < 0.05). Project type was a factor affecting only the duration of front-end planning between process projects and non-process projects. Process projects tended to have a longer median duration for front-end planning (29.2%) than non-process projects

(25.2%), and the difference was statistically significant at p=0.05 (U = 3103, z = -1.960, p = 0.05).

Light industrial projects spent the least time on average on front-end planning (23.7% of their overall duration) and engineering (34.6%), compared to heavy industrial projects, 31.7% and 42.3% respectively. On the other hand, these projects spent more time on construction (53.2%) and startup phases (22.8%), compared to heavy industrial projects, with 42.3%, and 7.7% respectively. Light industrial projects spent 15.1% more time on startup when compared with heavy industrial projects.

Project type was found to influence the durations of procurement and startup phases in light industrial projects significantly at $p<0.05$. The mean for procurement in pharmaceutical manufacturing projects was longer duration at 50.3% than in pharmaceutical laboratory projects at 46.6%, and the difference was statistically significant at $p<0.05$ (F (2,145) = 3.6, p = 0.03 < 0.05). Startup in pharmaceutical manufacturing projects took longer (24.4%) than startup in other light industrial projects (14.2%), and the difference in median was statistically significant at $p<0.05$ by a Kruskal-Wallis H test (X^2 (2) = 9.719, p = 0.008 < 0.05).

On average, industrial projects spent 46.9% of their overall duration on the construction phase, the longest phase, followed by procurement (46.2%), engineering (39.1%), front-end planning (15.5%), and then startup (14%). Heavy industrial projects spent 45.3% of their overall duration on the procurement phase, the longest phase, followed by engineering (42.3%), construction (42.3%), front-end planning (31.7%), and startup (7.7%) phases. Light industrial projects spent 53.2% of their overall duration on the construction phase, the longest phase, followed by procurement (47.6%), engineering (34.6%), front-end planning (23.7%), and startup (22.8%).

Table 4.6 Phase Duration in Percent Value for Industrial Projects

Category (Standard Deviation: S.D.)		Sample Size	Phases of the Project Development Life Cycle: Front-End-Planning	Detailed Engineering	Procure-ment	Construc-tion	Startup
Industry Group	Mean	355	28.4%	39.1%	46.2%	**<u>46.9%</u>**	14.0%
	S.D.		15.5%	15.5%	18.6%	**<u>17.0%</u>**	13.8%
	Median		**<u>25.3%</u>**	**<u>37.7%</u>**	45.4%	47.0%	**<u>9.3%</u>**
o Heavy Industrial Projects	Mean	207	31.7%	42.3%	45.3%	42.3%	7.7%
	S.D.		15.9%	14.7%	17.5%	16.4%	9.3%
	Median		**<u>29.2%</u>**	41.1%	44.7%	40.9%	4.1%
Process Projects	Mean	159	32.8%	41.5%	44.7%	42.8%	7.3%
	S.D.		16.0%	14.2%	18.0%	15.6%	9.4%
	Median		29.9%	40.7%	44.5%	40.9%	3.2%
Non-process Projects	Mean	48	28.4%	45.1%	47.0%	40.8%	8.9%
	S.D.		15.4%	16.4%	15.5%	19.1%	9.1%
	Median		25.2%	45.0%	46.5%	40.9%	6.3%
o Light Industrial Projects	Mean	148	23.7%	34.6%	**<u>47.6%</u>**	53.2%	22.8%
	S.D.		13.5%	15.4%	**<u>20.0%</u>**	15.7%	14.3%
	Median		21.4%	30.8%	46.6%	54.2%	**<u>20.2%</u>**
Pharmaceutical Manufacturing	Mean	95	22.8%	34.3%	50.3%	52.0%	25.4%
	S.D.		12.6%	14.2%	18.8%	15.8%	14.7%
	Median		21.1%	32.0%	47.9%	52.3%	24.4%
Pharmaceutical Laboratory	Mean	25	23.0%	28.8%	38.5%	57.5%	18.1%
	S.D.		15.4%	15.3%	19.2%	11.6%	9.5%
	Median		18.3%	22.7%	34.3%	59.0%	18.8%
Other Light Industrial Projects	Mean	28	27.6%	40.6%	46.6%	53.3%	18.2%
	S.D.		14.6%	17.8%	22.6%	18.5%	14.6%
	Median		25.9%	34.1%	48.2%	54.9%	14.2%

Bold in underline indicates a group that is statistically significant (p<0.05).

4.3.2 Heavy Industrial Projects

Table 4.7 presents percent mean phase duration for process projects, along with their standard deviation and median. Analysis was conducted to explore differences related to various project characteristics including project nature and size.

Construction durations were significantly influenced by project nature at p<0.05. Modernization projects tended to spend less time on the construction phase (36.8% in median), compared to grass root projects (45.5%), and the difference was statistically significant at p<0.05 by a Kruskal-Wallis H test (X^2 (2) = 6.774, p = 0.034 < 0.05). A similar trend was observed in startup durations: modernization projects spent less time (1.8% in median) than grass roots projects (6.9%), the difference was statistically significant at $p<0.05$ by a Kruskal-Wallis H test (X^2 (2) = 17.227, p = 0.000 < 0.05).

As project size increased, each phase spent more time except in the front-end planning and detailed engineering phases, on average. It was noticed that there was a decreasing trend of time spent on the front-end planning phase as the project size increased. Statistically, the project size did differentiate median values of construction duration in process projects. Projects costing $10MM-$50MM spent less time, 36.6%, compared to projects costing $100MM-$500MM, the difference amongst groups was statistically significant at $p<0.05$ by the Kruskal-Wallis H test (X^2 (2) = 9.838, p = 0.007 < 0.05). Process projects, on average, spent 44.7% of their overall duration on the procurement phase, the longest phase, followed by construction (42.8%), engineering (41.5%), front-end planning (32.8%), and startup (7.3%). Due to small sample size, comparison for non-process projects was not conducted.

Table 4.7 Phase Duration in Percent Value for Heavy Industrial Projects

Category (Standard Deviation: S.D.)		Sample Size	Phases of the Project Development Life Cycle				
			Front-End-Planning	Detailed Engineering	Procure-ment	Construc tion	Startup
Process Projects	Mean	159	32.8%	41.5%	44.7%	42.8%	7.3%
	S.D.		16.0%	14.2%	18.0%	15.6%	9.4%
	Median		29.9%	40.7%	44.5%	40.9%	3.2%
o Project Nature	Mean	159	32.8%	41.5%	44.7%	42.8%	7.3%
	S.D.		16.0%	14.2%	18.0%	15.6%	9.4%
	Median		29.9%	40.7%	44.5%	**<u>40.9%</u>**	**<u>3.2%</u>**
Grass Roots	Mean	38	31.2%	41.7%	43.0%	46.1%	9.4%
	S.D.		12.1%	14.4%	18.8%	12.9%	7.7%
	Median		29.6%	42.4%	42.7%	45.5%	6.9%
Addition	Mean	54	31.6%	43.0%	44.9%	45.3%	7.7%
	S.D.		17.1%	15.6%	16.5%	17.6%	10.3%
	Median		29.5%	42.3%	43.8%	41.6%	3.2%
Modernization	Mean	67	34.5%	40.3%	45.6%	38.9%	5.9%
	S.D.		17.0%	12.8%	18.9%	14.5%	9.4%
	Median		31.8%	38.6%	48.4%	36.8%	1.8%
o Project Size	Mean	159	32.8%	41.5%	44.7%	42.8%	7.3%
	S.D.		16.0%	14.2%	18.0%	15.6%	9.4%
	Median		29.9%	40.7%	44.5%	**<u>40.9%</u>**	3.2%
$10MM-$50MM	Mean	86	34.0%	39.7%	43.0%	39.9%	5.5%
	S.D.		17.3%	13.8%	18.3%	16.5%	7.3%
	Median		31.6%	39.3%	42.3%	36.6%	2.3%
$50MM-$100MM	Mean	26	33.1%	44.1%	45.2%	46.1%	8.6%
	S.D.		16.0%	13.5%	16.3%	15.8%	11.6%
	Median		30.9%	42.5%	45.4%	45.5%	3.2%
$100MM-$500MM	Mean	47	30.4%	43.4%	47.5%	46.2%	10.0%
	S.D.		13.3%	14.9%	18.4%	12.6%	10.8%
	Median		28.4%	43.1%	47.9%	47.2%	6.2%
Non-process Projects	Mean	48	28.4%	45.1%	47.0%	40.8%	8.9%
	S.D.		15.4%	16.4%	15.5%	19.1%	9.1%
	Median		25.2%	45.0%	46.5%	40.9%	6.3%
Addition	Mean	20	29.1%	41.3%	39.3%	44.7%	11.3%
	S.D.		15.0%	15.3%	13.9%	17.0%	7.3%
	Median		24.9%	35.2%	40.0%	43.7%	10.0%
$100MM-$500MM	Mean	22	30.0%	46.7%	50.0%	46.3%	11.0%
	S.D.		15.9%	16.3%	14.3%	12.0%	10.7%
	Median		26.3%	45.3%	51.7%	44.6%	8.2%

Bold in underline indicates a group that is statistically significant ($p<0.05$).

4.3.3 Light Industrial Projects

Table 4.8 presents percent mean phase durations for pharmaceutical manufacturing, along with their standard deviation and median.

The table demonstrates how each phase's percent mean (or median) duration differed by various project characteristics including project nature and size. Analysis results show that project nature affects duration of startup significantly. Addition projects spent less time (15.5%), compared to other project types (25.5% for grass roots projects; 29.2% for modernization projects). The difference in median amongst groups was statistically significant at $p<0.05$ by a Kruskal-Wallis H test (X^2 (2) = 10.336, p = 0.006 < 0.05). As project size increased, most phases increased as well, on average, except for the engineering and procurement phases. Nonetheless, project size did not differentiate phase durations significantly. The pharmaceutical manufacturing projects, on average, spent 52% of their overall duration on the construction phase, the longest phase, followed by the procurement (50.3%), engineering (34.3%), startup (25.4%), and front-end planning (22.8%). Interestingly, pharmaceutical manufacturing projects spent 2.6% more time on the startup phase, on average, compared to the time used for front-end planning.

Table 4.8 Phase Duration in Percent Value for Pharmaceutical Manufacturing Projects

Category (Standard Deviation: S.D.)		Sample Size	Phases of the Project Development Life Cycle: Front-End-Planning	Detailed Engineering	Procure-ment	Construc-tion	Startup
Pharmaceutical Manufacturing	Mean	95	22.8%	34.3%	50.3%	52.0%	25.4%
	S.D.		12.6%	14.2%	18.8%	15.8%	14.7%
	Median		21.1%	32.0%	47.9%	52.3%	24.4%
Project Nature	Mean	95	22.8%	34.3%	50.3%	52.0%	25.4%
	S.D.		12.6%	14.2%	18.8%	15.8%	14.7%
	Median		21.1%	32.0%	47.9%	52.3%	**<u>24.4%</u>**
Grass Roots	Mean	33	21.3%	31.9%	47.9%	55.4%	27.7%
	S.D.		10.2%	11.4%	15.5%	15.5%	14.3%
	Median		20.7%	32.1%	46.3%	58.6%	25.5%
Addition	Mean	27	24.6%	32.1%	51.3%	48.6%	17.7%
	S.D.		15.6%	14.2%	19.0%	14.9%	10.9%
	Median		20.6%	28.8%	49.7%	47.8%	15.5%
Modernization	Mean	35	22.6%	38.4%	51.7%	51.6%	29.2%
	S.D.		12.2%	16.0%	21.5%	16.5%	15.6%
	Median		22.2%	37.9%	50.8%	56.2%	29.2%
Project Size	Mean	95	32.8%	41.5%	44.7%	42.8%	7.3%
	S.D.		12.6%	14.2%	18.8%	15.8%	14.7%
	Median		21.1%	32.0%	47.9%	52.3%	24.4%
$10MM-$50MM	Mean	29	20.9%	29.4%	47.1%	47.7%	23.9%
	S.D.		12.6%	14.0%	18.5%	13.1%	15.7%
	Median		19.7%	28.7%	46.8%	47.0%	21.9%
$50MM-$100MM	Mean	30	22.1%	38.1%	52.4%	53.8%	24.6%
	S.D.		11.9%	13.5%	20.2%	16.9%	14.4%
	Median		20.6%	37.0%	48.2%	54.7%	22.0%
$100MM-$500MM	Mean	36	24.8%	35.1%	51.0%	54.0%	27.3%
	S.D.		13.1%	14.2%	18.0%	16.5%	14.2%
	Median		22.8%	32.2%	51.8%	58.5%	28.1%
Pharmaceutical Laboratory	Mean	25	23.0%	28.8%	38.5%	57.5%	18.1%
	S.D.		15.4%	15.3%	19.2%	11.6%	9.5%
	Median		18.3%	22.7%	34.3%	59.0%	18.8%
Other Light Industrial Projects	Mean	28	27.6%	40.6%	46.6%	53.3%	18.2%
	S.D.		14.6%	17.8%	22.6%	18.5%	14.6%
	Median		25.9%	34.1%	48.2%	54.9%	14.2%

Bold in underline indicates a group that is statistically significant (p<0.05).

4.4. PHASE ARRANGEMENT IN THE PROJECT DEVELOPMENT LIFE CYCLE

Figure 4.1 provides an aggregate illustration of the data set demonstrating how the five main phases were arranged in the overall duration. A total of 355 industrial projects were used in this analysis, and each phase schedule date was included. The phase arrangement, shown below, contains average start time, end time, and duration in percent value, along with its sequence for each phase. In addition, it includes the variation of each phase's start and end time with percent values at the end of the each line. For example, the front-end planning phase started at 0% as a project was initiated and ended at 28.4% of the overall duration, on average. The mean duration of the phase was the same as its mean end time, 28.4%. The 66.8% value at the end of the line indicates that there was a project in which the front-end planning phase was completed at 66.8% of the overall duration. The extent of concurrency, on average, was 36.9% of the overall duration between the engineering and procurement phases, where 36.9% = 65.5%-28.7%, followed by 18.9% between the engineering and construction phases. It is noticeable that the average percent completion of the engineering phase prior to the construction phase start for industrial projects was 51.6% based on the engineering phase duration, where 51.6% = (46.7%-26.5%)/(65.6%-26.5%). The longest phase was the construction phase (Duration (D) =46.9% and Start time (S)=46.7%), followed by the procurement phase (D=46.2% and S=28.7%), and the engineering phase (D=39.1% and S=26.5%).

In the previous sections, the industry group turned out to be a major factor differentiating each phase's start time and duration. Regarding this fact, two phase arrangements in the project development life cycle were constructed for heavy and light industrial projects (Figures 4.2 and 4.3) with the same components used for Figure 4.1. A total of 207 projects were analyzed to construct the phase arrangement for heavy industrial projects, and the remaining (148 projects) were light industrial projects.

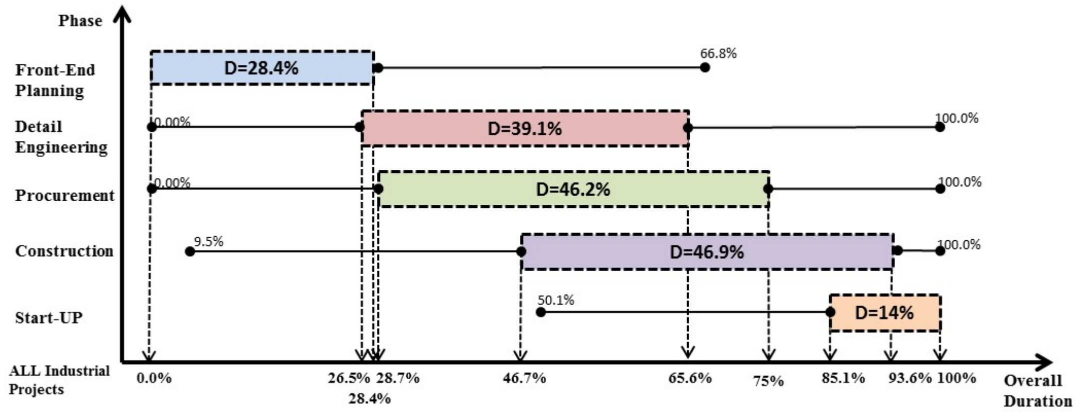


Figure 4.1 Phase Arrangement in the Project Development Life Cycle for the Industrial Projects

For heavy industrial projects, the extent of concurrency on average, was 41% of the overall duration, found between the engineering and procurement phases, followed by 19.7% between the engineering and construction phases. It is also noticeable that the average percent completion of the engineering phase prior to the construction phase start for industrial projects was 53.5% based on the engineering phase duration, where 53.5% = (53.1%-30.4%)/(72.8%-30.4%). The longest phase was the procurement phase (D =45.3% and S=31.9%), followed by the engineering phase (D=42.34% and S=30.4%), and the construction phase (D=42.32% and S=53.1%).

For light industrial projects, the extent of concurrency on average, was 31.4% of the overall duration between the engineering and procurement phases, followed by 17.8% between the engineering and construction phases. The average percent completion of the engineering phase prior to the construction phase start for industrial projects was 48.6 % based on engineering phase duration, where 48.6% = (37.8%-21%)/(55.6%-21%). The longest phase was the construction phase (D=53.2% and S=38.8%), followed by the procurement phase (D=47.6% and S=24.2%), and the engineering phase (D=34.6% and S=21%).

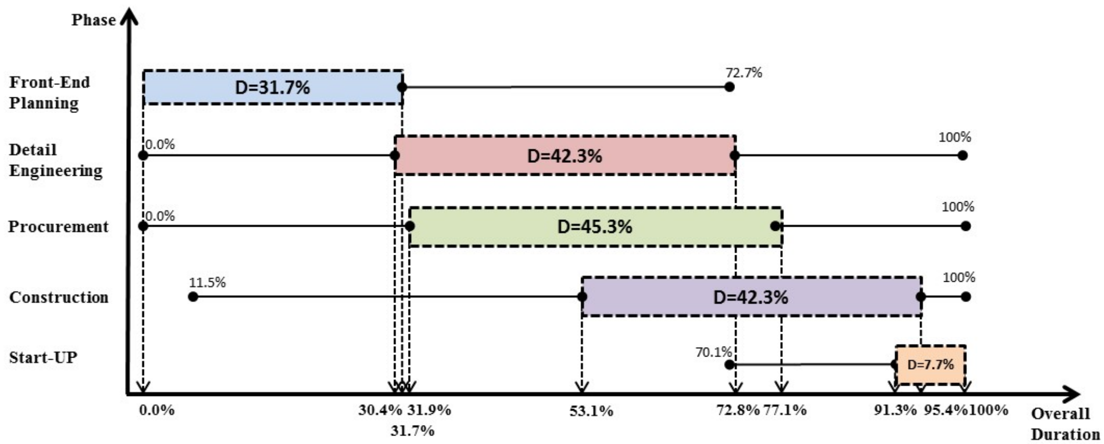


Figure 4.2 Phase Arrangement in the Project Development Life Cycle for the Heavy Industrial Projects

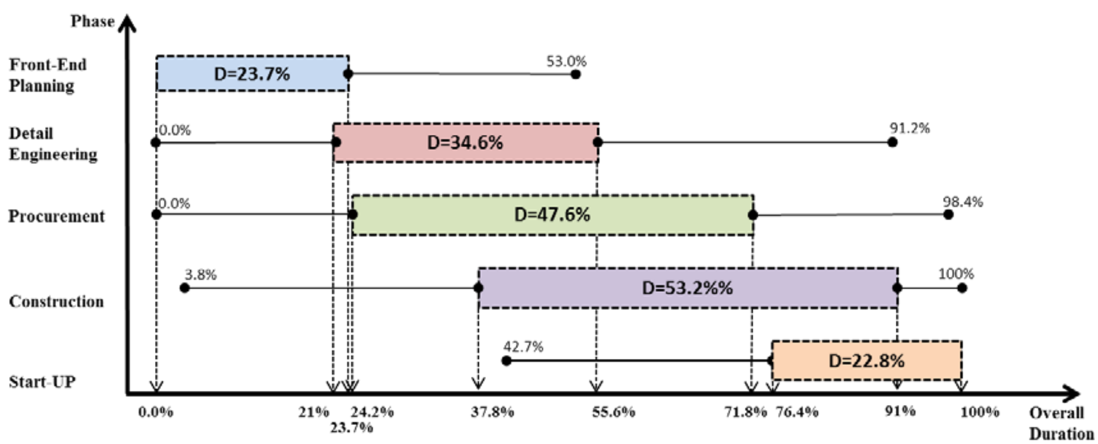


Figure 4.3 Phase Arrangement in the Project Development Life Cycle for the Light Industrial Projects

4.5 SUMMARY AND CONCLUSION

The analysis and discussion in this chapter was intended to answer the first research question: “How can project development life cycle phase arrangement and duration be quantified by various projects characteristics?” The research question was accomplished throughout the process defined in Chapter 3 and the research results presented in Chapter 4.

The first research question was designed to characterize and quantify phase arrangement of the project development life cycle by analyzing collected schedule data employed in industrial projects submitted to CII. To do so, quantification of each phase’s start time and duration of the collected projects was essential input to characterize the phase arrangement. Phase arrangement is defined as the relative position and sequence of the phases employed in the project development life cycle. Since all projects were built at various times and had different durations, a normalization process was necessary before quantification. The normalization process includes conversion of a phase’s start time and duration to certain percent values, with zero as project initiation and 100% as project completion. Project characteristics that might influence the variables were employed to classify a series of phase arrangements at a more detailed level. The underlying hypothesis was that there are certain project characteristics that affect either a phase’s start time or duration significantly. The industry group, project type, nature, and size were selected as project characteristics. Among them, industry group turned out being a major factor, differentiating a phase’s start time and duration. Based on the quantification results, the phase arrangement was constructed. A summary of the quantification results regarding phase’ start time and duration is provided below.

- Industry group significantly impacts a phase's start time and duration at $p < 0.05$. The front-end planning phase was excluded from this analysis by definition. The procurement duration was significantly equal for both heavy and light industrial projects.
- Project type was a factor affecting only the detailed engineering phase's start time and was also a factor affecting the duration of front-end planning in heavy industrial projects; the start times of the procurement and startup phases were differentiated by project type in light industrial projects. In addition, the durations of the procurement and startup phases were affected by project type as well, with significance at $p<0.05$.
- The extent of concurrency, on average, was 36.9% of the overall duration between the engineering and procurement phases, followed by 18.9% between the engineering and construction phases. The average percent completion of the engineering phase prior to the construction phase start for industrial projects was 51.6% based on the engineering phase duration. The longest phase was the construction phase (Duration (D) =46.9% and with a start time (S)=46.7%), followed by the procurement phase (D=46.2% and S=28.7%), and then the engineering phase (D=39.1% and S=26.5%).
- For heavy industrial projects: the extent of concurrency, on average, was 41% of the overall duration found between the engineering and procurement phases, followed by 19.7% between the engineering and construction phases. The average percent completion of the engineering phase prior to the construction phase start for industrial projects was 53.5% based on the engineering phase duration. The longest phase was the procurement phase

(D =45.3% and S=31.9%), followed by the engineering phase (D=42.34% and S=30.4%), and the construction phase (D=42.32% and S=53.1%).

- For light industrial projects: the extent of concurrency, on average, was 31.4% of the overall duration between the engineering and procurement phases, followed by 17.8% between the engineering and construction phases. The average percent completion of the engineering phase prior to the construction phase start for industrial projects was 48.6% based on the engineering phase duration. The longest phase was the construction phase (D=53.2% and S=38.8%), followed by the procurement phase (D=47.6% and S=24.2%), and the engineering phase (D=34.6% and S=21%).

Phase arrangement effectively demonstrates the relative position and sequence of phases of a project's overall duration, but it is not sufficient to explain the detailed level of phase arrangements where sequential, parallel, or reversed sequential patterns exist. The long tails of each phase shown in Figures 4.1, 4.2, and 4.3 are the evidence of this fact. To examine those efficiently, the phase arrangement needs to be broken down with consideration of the start and end times of the phases. Chapter 5 describes this process and identifies which phase arrangements are most common.

CHAPTER 5: IDENTIFICATION OF PHASE ARRANGEMENT PATTERNS

5.1 INTRODUCTION

This chapter describes how the phase arrangements in the project development life cycle can be broken down into pieces only containing the phase arrangement of two or three phases. In Chapter 3, a few conceptual phase arrangements such as sequential, parallel, and reversed sequential phase arrangements were explained, but it was not confirmed how frequently those arrangements were employed in real projects. The underlying hypothesis is that there are commonly used phase arrangements in a combination of phases, rather than a sequential arrangement, as shown in the phase arrangement in the project development life cycle. The combination of phases is presumably related to each other: e.g., the front-end planning and engineering phases or the front-end planning and procurement phases since those phases provide and receive significant amounts of information, as opposed to front-end planning and construction phases for example or front-end planning and startup phases.

The phase arrangements (patterns) of the two phases or three phases share the same components as used in the phase arrangement in the project development life cycle: the start time, the end time, and duration. However, the phase arrangements of the pairwise or triple-wise phases are squared focusing on the detailed level of phase sequences. The first task was to identify patterns of phases based on their start and end dates with consideration for conceptual phase arrangements. The next task involves to quantifying the frequencies of each pattern in the combination of phases. As an output, common patterns across phases were identified. Furthermore, rare but existing patterns were recognized.

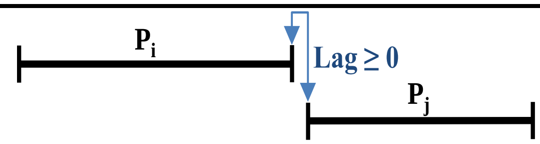
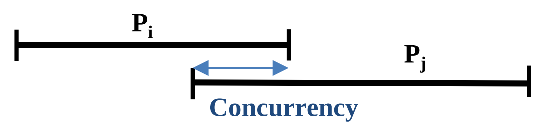
5.2 IDENTIFICATION OF THE PAIRWISE PHASE ARRANGEMENT PATTERNS

At the phase level, the sequences of phases are categorized as sequential, parallel, and reversed sequential. The sequential sequence is the one typically defined as the finish to start relationship with a certain level of concurrency starting from zero, but succeeding phases should be completed after the preceding phase is completed. The parallel sequence is one in which the phases are performed in parallel most of the time, and either of the phases' duration is absorbed into its counterpart which means that the phase's absorbed duration does not contribute to any increase or decrease of the overall duration of the two phases. The reversed sequential sequence is that a succeeding phase, defined in a conventional process, is started early before a preceding phase starts.

Table 5.1 illustrates the eleven patterns identified from all possible combinations of phases, as follows: front-end planning (the preceding phase) and engineering, procurement, construction, or startup phases; engineering (the preceding phase) and procurement, construction, or startup phases; procurement (the preceding phase) and construction, or startup phases; construction (the preceding phase) and startup phases. The patterns were identified from the conceptually defined patterns, but those were further broken down into pieces allowing concurrency of phase start date, and phase end date. In detail, the start dates were broken down into early start, the same start, and late start of the succeeding phase. Similarly, the end dates were broken down into early completion, completion at the same time, and late completion of the succeeding phase.

As shown in Table 5.1, pattern 1 and pattern 2 are classified as sequential. Patterns 3 through 7 are parallel. Patterns 8 to 11 show reversed sequential pattern.

Table 5.1 Descriptions of Patterns and Their Graphical Illustration

<table>
<tr><td>Description of pattern</td><td>Phase Arrangement Patterns includes:
(P_i : the preceding phase and P_j: the succeeding phase)</td></tr>
<tr><td>Pattern 1: Sequential arrangement of two phases without concurrency: conventional phase arrangement</td><td>
</td></tr>
<tr><td>Pattern 2: Sequential arrangement of two phases with concurrency</td><td>
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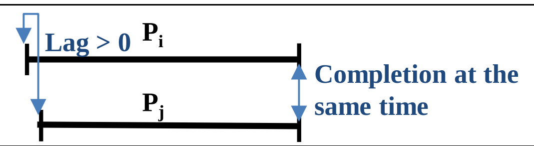
<tr><td>Pattern 3: Parallel arrangement of two phases with the same completion time</td><td>
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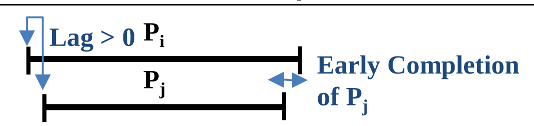
<tr><td>Pattern 4: Parallel arrangement of two phases with longer predecessor</td><td>
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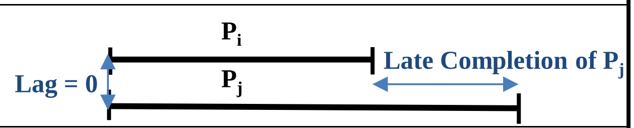
<tr><td>Pattern 5: Parallel arrangement of two phases with the same start time and longer successor</td><td>
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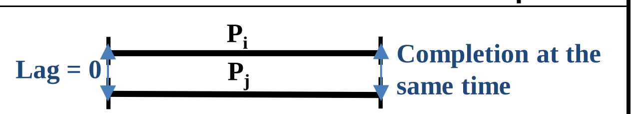
<tr><td>Pattern 6: Parallel arrangement of two phases with the same start and stop times</td><td>
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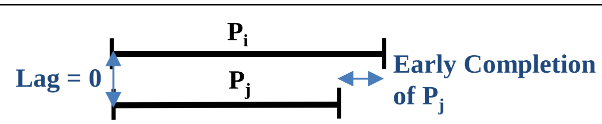
<tr><td>Pattern 7: Parallel arrangement of two phases with the same start time and longer predecessor</td><td>
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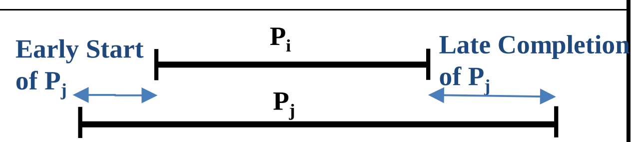
<tr><td>Pattern 8: Reversed sequential arrangement of two phases with concurrency and longer successor</td><td>
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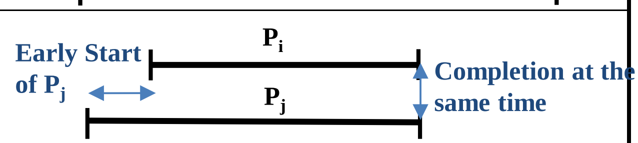
<tr><td>Pattern 9: Reversed sequential arrangement of two phases with concurrency and the same stop time</td><td>
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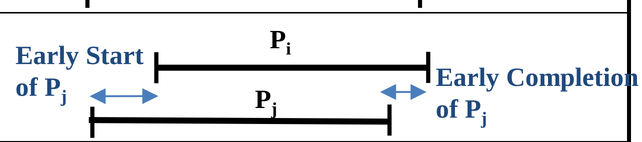
<tr><td>Pattern 10: Reversed sequential arrangement of two phases with concurrency</td><td>
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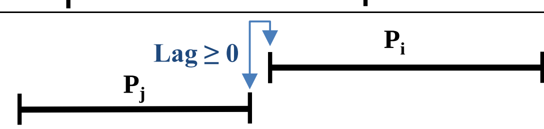
<tr><td>Pattern 11: Reversed sequential arrangement of two phases without concurrency</td><td>
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5.3 FREQUENCIES OF THE PAIRWISE PHASE ARRANGEMENT PATTERNS

5.3.1 Industrial Projects

Table 5.2 illustrates the frequencies of the pairwise patterns for all collected industrial projects. The green shading indicates the pattern most frequently utilized and the white color indicates patterns they were rarely used. Frequency is represented as a percent value of the number of projects that used the pattern out of the given sample size. The six phase combinations that are most closely related to each other due to their strong information flow are shown. For example, during front-end planning and procurement phases the procurement team starts working on the purchase order once the long lead and standardized items have been identified. In this case, the procurement phase starts earlier than conventionally practice.

As shown in the table, front-end planning and engineering (FEP-ENG) were most frequently connected in pattern 1 (64.8%), the sequential arrangement of two phases without concurrency between two phases, followed by the pattern 2 (32.4%), the sequential arrangement of two phases with concurrency. Similarly, the same trend appeared on the front-end planning and procurement phases with 61.7% in pattern 1 and 35.2% in pattern 2. On the contrary, the engineering and procurement phases (ENG-PRO) were most frequently paired in pattern 2 (79.4%), followed by the pattern 1 (14.1%). The same trend was noticed on the procurement and construction phases (PRO-CON). Interestingly, the construction and startup phases (CON-STARTUP) showed the same proportion in pattern 1 (41.1%) and pattern 2 (41.1%). Furthermore, the engineering and procurement phases (ENG-PRO) were found to have utilized all possible phase arrangements: the sequential patterns (patterns 1 and pattern 2) were most frequently observed at 40%, followed by the reversed sequential patterns (pattern 8 through pattern 10) at 30.4%, and by the parallel patterns (pattern 3 through pattern 7) at 29.7%. Interestingly, 3.7% of projects experienced an early start of the construction phase before the engineering phase started and 3.1% of projects had an early completion of the construction phase before the procurement phase was completed.

Table 5.2 Frequency of the Pairwise Phase Patterns for Industrial Projects

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern1-Sequential arrangement of two phases w/o concurrency	355	64.8%	61.7%	4.5%	14.1%	7.9%	41.1%
Pattern2-Sequential arrangement of two phases w/ concurrency	355	32.4%	35.2%	35.5%	79.4%	77.2%	41.1%
Pattern3-Parallel arrangement of two phases w/ exact same stop	355	0.8%		2.3%	0.3%	1.1%	7.3%
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	355	0.8%	1.1%	11.3%	1.4%	3.1%	9.9%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	355	0.8%	1.7%	9.3%	1.1%	2.3%	
Pattern6-Parallel arrangement of two phases with exact same start and stop	355	0.3%	0.3%	2.3%		0.3%	0.3%
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	355			4.5%			
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	355			17.7%	3.4%	7.9%	0.3%
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	355			3.1%		0.3%	
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	355			8.5%	0.3%		
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	355			1.1%			

A similar trend was noticed in heavy industrial projects, as shown in Table 5.3. Pattern 1 was the most frequently employed pattern in both FEP-ENG (64.7%) and FEP-PRO (61.4%). Pattern 2 demonstrated high frequency on ENG-CON (81.2%) and PRO-CON (80.2%). On the other hand, The CON-STARTUP showed a different pattern from industrial projects overall, in that the pattern 1 was employed more than 60% of the time. An interesting point was found in the ENG-PRO, where 35.7% of the projects used parallel patterns, followed by 32.8% used reversed sequential patterns and 31.4% employed sequential patterns. Only 2.9% of the projects experienced an early start of the construction phase before engineering started. Among those, 0.5% of the projects, reported that the construction phase was completed before the engineering phase completed. Furthermore, 0.5% of the projects experienced early completion the construction before the procurement phase was completed, as shown in pattern 4 with PRO-CON.

Table 5.3 Frequency of the Pairwise Phase Patterns for Heavy Industrial Projects

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern1-Sequential arrangement of two phases w/o concurrency	207	64.7%	61.4%	3.4%	13.0%	10.1%	61.4%
Pattern2-Sequential arrangement of two phases w/ concurrency	207	32.9%	36.2%	28.0%	81.2%	80.2%	21.7%
Pattern3-Parallel arrangement of two phases w/ exact same stop	207	1.0%		2.9%	0.5%	1.0%	5.8%
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	207	1.0%	1.9%	15.9%	1.9%	0.5%	11.1%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	207	0.5%		8.7%	0.5%	0.5%	
Pattern6-Parallel arrangement of two phases with exact same start and stop	207		0.5%	2.4%		0.5%	
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	207			5.8%			
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	207			15.9%	2.4%	7.2%	
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	207			3.4%			
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	207			12.1%	0.5%		
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	207			1.4%			

Table 5.4 presents the frequency for light industrial projects where similar trends were observed. Pattern 1 was the most frequently employed pattern in both FEP-ENG (64.9%) and FEP-PRO (62.2%). Pattern 2 demonstrated high frequency on ENG-CON (77%) and PRO-CON (73%). In contrast, CON-STARTUP showed a different pattern from heavy industrial projects. In this case, pattern 2 was employed at 68.2%. 52% of the projects used parallel patterns in ENG-PRO, followed by 27.1% for reversed sequential patterns and by 20.9% for parallel patterns. In addition, 0.7% of the projects had a longer duration of startup phase than the construction phase, meaning that the startup phase started early, even before the construction phase started.

Table 5.4 Frequency of the Pairwise Phase Patterns for Light Industrial Projects

Description of Pattern	**Sample Size**	**FEP-ENG**	**FEP-PRO**	**ENG-PRO**	**ENG-CON**	**PRO-CON**	**CON-STARTUP**
Pattern1-Sequential arrangement of two phases w/o concurrency	148	64.9%	62.2%	6.1%	15.5%	4.7%	12.8%
Pattern2-Sequential arrangement of two phases w/ concurrency	148	31.8%	33.8%	45.9%	77.0%	73.0%	68.2%
Pattern3-Parallel arrangement of two phases w/ exact same stop	148	0.7%		1.4%		1.4%	9.5%
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	148	0.7%		4.7%	0.7%	6.8%	8.1%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	148	1.4%	4.1%	10.1%	2.0%	4.7%	
Pattern6-Parallel arrangement of two phases with exact same start and stop	148	0.7%		2.0%			0.7%
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	148			2.7%			
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	148			20.3%	4.7%	8.8%	0.7%
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	148			2.7%		0.7%	
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	148			3.4%			
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	148			0.7%			

5.3.2 Heavy Industrial Projects

5.3.2.1 Process and Non-process projects

Table 5.5 describes the frequency of patterns for process projects. Pattern 1 was the most frequently employed in both FEP-ENG (65.4%) and FEP-PRO (60.4%). Pattern 2 showed the highest frequency on ENG-CON (84.3%) and PRO-CON (81.8%). CON-STARTUP showed a similar pattern as in heavy industrial projects, which was that the pattern was employed at 59% of the projects. In ENG-PRO, 36.6% of the projects used reversed sequential patterns, which was the highest frequency, followed by 35.8% for parallel patterns and 27.4% for sequential patterns. A total of 2.5% of projects experienced an early start of the construction phase before the engineering phase started. In addition, 1.3% of the projects reported completion of the procurement phase before the engineering phase was completed.

Table 5.5 Frequency of the Pairwise Phase Patterns for Process Projects

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern1-Sequential arrangement of two phases w/o concurrency	159	65.4%	60.4%	4.4%	10.1%	8.8%	59.1%
Pattern2-Sequential arrangement of two phases w/ concurrency	159	32.7%	37.1%	23.3%	84.3%	81.8%	20.8%
Pattern3-Parallel arrangement of two phases w/ exact same stop	159	1.3%		3.1%	0.6%	0.6%	7.5%
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	159	0.6%	1.9%	16.4%	1.9%		12.6%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	159			7.5%	0.6%	0.6%	
Pattern6-Parallel arrangement of two phases with exact same start and stop	159		0.6%	1.9%		0.6%	
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	159			6.9%			
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	159			16.4%	2.5%	7.5%	
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	159			4.4%			
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	159			14.5%			
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	159			1.3%			

Table 5.6 demonstrates the frequency of patterns employed in non-process projects. Pattern 1 was the most frequently employed pattern in both FEP-ENG (62.5%) and FEP-PRO (64.6%). Pattern 2 showed the highest frequency both on ENG-CON (70.8%) and PRO-CON (75%). CON-STARTUP showed a similar pattern as the process projects, which was that pattern 1 was employed at 68.8% of the projects. In ENG-PRO, 43.8% of the projects used the sequential patterns, which was the highest frequency, followed by 35.5% for the parallel patterns and by 20.9% for the reversed sequential patterns. This was

an opposite trend from that observed in process projects. A total of 2.1% of projects experienced an early start of the construction phase before the engineering phase started. Similarly, 2.1% completed the procurement phase before the engineering phase was completed.

Table 5.6 Frequency of the Pairwise Phase Patterns for Non-process Projects

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern1-Sequential arrangement of two phases w/o concurrency	48	62.5%	64.6%		22.9%	14.6%	68.8%
Pattern2-Sequential arrangement of two phases w/ concurrency	48	33.3%	33.3%	43.8%	70.8%	75.0%	25.0%
Pattern3-Parallel arrangement of two phases w/ exact same stop	48			2.1%		2.1%	
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	48	2.1%	2.1%	14.6%	2.1%	2.1%	6.3%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	48	2.1%		12.5%			
Pattern6-Parallel arrangement of two phases with exact same start and stop	48			4.2%			
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	48			2.1%			
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	48			14.6%	2.1%	6.3%	
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	48						
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	48			4.2%	2.1%		
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	48			2.1%			

5.3.2.2 Project Nature

Tables 5.7 through 5.9 presents the frequency of patterns by project nature. In this research, project nature is categorized into grass roots, addition, and modernization. As shown in the tables, project nature did not correlate with meaningful change in phase arrangement, as compared to project type. More than 63% of projects employed pattern 1, which was the most commonly used pattern, for FEP-ENG across the three project natures. More than 63% of projects utilized pattern 1 for FEP-PRO in addition and modernization projects, whereas grass roots projects showed increased usage of pattern 2 (46.3%), leading to a decrease in frequency of pattern 1 (51.9%). In addition, more than 77% of the projects used pattern 2 for ENG-CON and PRO-CON in all three categories. An interesting point was found in the ENG-PRO pattern: grass roots projects had a high implementation of reversed sequential patterns (39%); and modernization and addition projects had high usage of parallel patterns, 37% and 39% respectively (Figure 5.1).

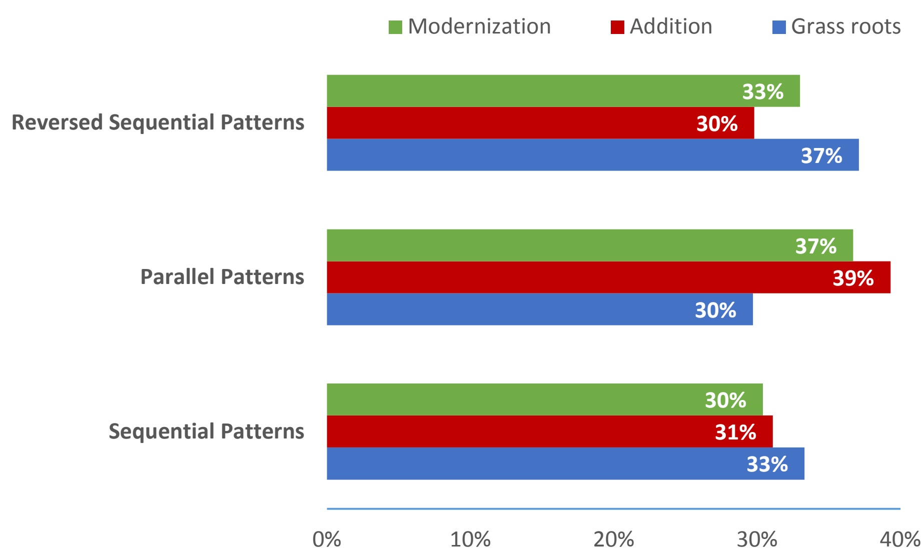


Figure 5.1 Patterns' Frequencies Used for the ENG-PRO by Project Nature

Table 5.7 Frequency of the Pairwise Phase Patterns for Grass Roots Projects

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern1-Sequential arrangement of two phases w/o concurrency	54	64.8%	51.9%	3.7%	7.4%	11.1%	59.3%
Pattern2-Sequential arrangement of two phases w/ concurrency	54	35.2%	46.3%	29.6%	90.7%	77.8%	37.0%
Pattern3-Parallel arrangement of two phases w/ exact same stop	54			3.7%			1.9%
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	54		1.9%	9.3%	1.9%		1.9%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	54			3.7%		1.9%	
Pattern6-Parallel arrangement of two phases with exact same start and stop	54			3.7%			
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	54			9.3%			
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	54			22.2%		9.3%	
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	54			1.9%			
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	54			11.1%			
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	54			1.9%			

Table 5.8 Frequency of the Pairwise Phase Patterns for Addition Projects

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern1-Sequential arrangement of two phases w/o concurrency	74	66.2%	66.2%	2.7%	12.2%	8.1%	58.1%
Pattern2-Sequential arrangement of two phases w/ concurrency	74	29.7%	29.7%	28.4%	78.4%	82.4%	20.3%
Pattern3-Parallel arrangement of two phases w/ exact same stop	74			1.4%		1.4%	6.8%
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	74	2.7%	2.7%	21.6%	2.7%		14.9%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	74	1.4%		10.8%	1.4%		
Pattern6-Parallel arrangement of two phases with exact same start and stop	74		1.4%	4.1%			
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	74			1.4%			

Table 5.8 Frequency of the Pairwise Phase Patterns for Addition Projects (Continued)

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	74			12.2%	4.1%	8.1%	
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	74			2.7%			
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	74			12.2%	1.4%		
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	74			2.7%			

Table 5.9 Frequency of the Pairwise Phase Patterns for Modernization Projects

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern1-Sequential arrangement of two phases w/o concurrency	79	63.3%	63.3%	3.8%	17.7%	11.4%	65.8%
Pattern2-Sequential arrangement of two phases w/ concurrency	79	34.2%	35.4%	26.6%	77.2%	79.7%	12.7%
Pattern3-Parallel arrangement of two phases w/ exact same stop	79	2.5%		3.8%	1.3%	1.3%	7.6%
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	79		1.3%	15.2%	1.3%	1.3%	13.9%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	79			10.1%			
Pattern6-Parallel arrangement of two phases with exact same start and stop	79					1.3%	
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	79			7.6%			
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	79			15.2%	2.5%	5.1%	
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	79			5.1%			
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	79			12.7%			
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	79						

5.3.2.3 Project Size

Tables 5.10 through 5.12 present the frequency of patterns by project size. In this research, the project size was categorized as $10MM-$50MM, $50MM-$100MM, and $100MM-$500MM. As shown in the tables, project size did not correlate with meaningful differences, as compared to those shown in sections regarding project type and project nature. More than 59% of the projects employed pattern 1. It was the most commonly used pattern for FEP-ENG in the three project sizes. More than 52% of the projects utilized pattern 1 for FEP-PRO. In addition, more than 71% of the projects used pattern 2 for ENG-CON and PRO-CON in all three categories. An interesting fact was found in ENG-PRO projects costing $10MM-$50MM: these projects had a high implementation of sequential patterns (39%). As project size increased, the projects tended to employ parallel and reversed sequential patterns with more than 10% increased from sequential patterns. Specifically, medium-size projects ($50MM-$100MM) showed the highest usage of parallel patterns (Figure 5.2).

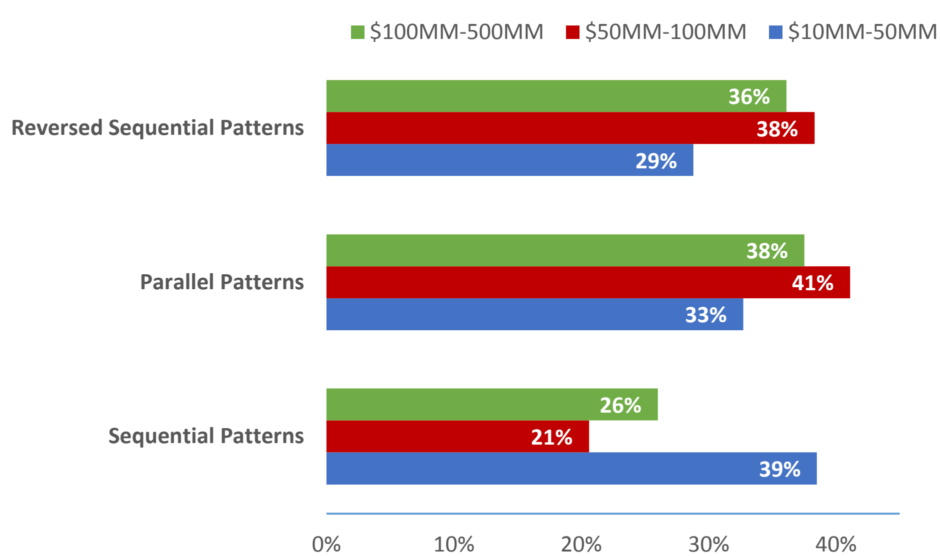


Figure 5.2 Patterns' Frequencies Used for the ENG-PRO by Project Size

Table 5.10 Frequency of the Pairwise Phase Patterns for $10MM-$50MM Projects

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern1-Sequential arrangement of two phases w/o concurrency	104	68.3%	65.4%	5.8%	21.2%	13.5%	69.2%
Pattern2-Sequential arrangement of two phases w/ concurrency	104	26.9%	33.7%	32.7%	71.2%	76.0%	11.5%
Pattern3-Parallel arrangement of two phases w/ exact same stop	104	1.9%		1.9%	1.0%		3.8%
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	104	1.9%	1.0%	17.3%	1.0%		15.4%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	104	1.0%		7.7%	1.0%		
Pattern6-Parallel arrangement of two phases with exact same start and stop	104					1.0%	
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	104			5.8%			
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	104			10.6%	3.8%	9.6%	
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	104			3.8%			
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	104			14.4%	1.0%		
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	104						

Table 5.11 Frequency of the Pairwise Phase Patterns for $50MM-$100MM Projects

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern1-Sequential arrangement of two phases w/o concurrency	34	55.9%	52.9%			8.8%	61.8%
Pattern2-Sequential arrangement of two phases w/ concurrency	34	44.1%	41.2%	20.6%	94.1%	79.4%	17.6%
Pattern3-Parallel arrangement of two phases w/ exact same stop	34			5.9%			8.8%
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	34		2.9%	17.6%	5.9%	2.9%	11.8%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	34			14.7%		2.9%	
Pattern6-Parallel arrangement of two phases with exact same start and stop	34		2.9%				

Table 5.11 Frequency of the Pairwise Phase Patterns for $50MM-$100MM Projects (Continued)

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	34			2.9%			
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	34			14.7%		5.9%	
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	34			5.9%			
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	34			11.8%			
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	34			5.9%			

Table 5.12 Frequency of the Pairwise Phase Patterns for $100MM-$500MM Projects

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern1-Sequential arrangement of two phases w/o concurrency	69	63.8%	59.4%	1.4%	7.2%	5.8%	49.3%
Pattern2-Sequential arrangement of two phases w/ concurrency	69	36.2%	37.7%	24.6%	89.9%	87.0%	39.1%
Pattern3-Parallel arrangement of two phases w/ exact same stop	69			2.9%		2.9%	7.2%
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	69		2.9%	13.0%	1.4%		4.3%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	69			7.2%			
Pattern6-Parallel arrangement of two phases with exact same start and stop	69			7.2%			
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	69			7.2%			
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	69			24.6%	1.4%	4.3%	
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	69			1.4%			
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	69			8.7%			
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	69			1.4%			

5.3.3 Light Industrial Projects

5.3.3.1 Pharmaceutical Manufacturing, Pharmaceutical Laboratory, and Other Industrial Projects

Table 5.13 summarizes the frequency of patterns used by pharmaceutical manufacturing projects. The overall trend was not significantly different from light industrial projects. Pattern 1 was the most frequently employed pattern in both FEP-ENG (65.3%) and FEP-PRO (57.9%). Pattern 2 demonstrated high frequency for ENG-CON (77.9%) and PRO-CON (72.6%) and CON-STARTUP, (73.7%). A total of 44% of the projects used sequential patterns in ENG-PRO, followed by 37% with reversed sequential patterns and 19% with parallel patterns. It was found that 6.3% of the projects initiated early start of the construction phase before the engineering phase started.

Table 5.14 presents the frequency of patterns used by pharmaceutical laboratory projects. The overall trend did not demonstrate a meaningful difference from light industrial projects. Pattern 1 was the most frequently employed pattern in both FEP-ENG (76%) and FEP-PRO (84%). Pattern 2 demonstrated high frequency for ENG-CON (80%) and PRO-CON (68%). CON-STARTUP showed 64% of projects using pattern 2. Further, 80% of the projects used sequential patterns in ENG-PRO, followed by 16% using parallel patterns and 4% with reversed sequential patterns.

Table 5.15 presents the frequency of patterns used by light industrial projects. Pattern 1 was the most frequently employed pattern in both FEP-ENG (53.6%) and FEP-PRO (57.1%). Pattern 2 demonstrated high frequency on ENG-CON (71.4%) and PRO-CON (78.6%). The CON-STARTUP combination showed that 53.6% of projects used pattern 2. In terms of sequence, 54% of the projects used the sequential pattern in ENG-PRO, followed by 32% used the parallel pattern and 14% used the reversed sequential pattern.

An interesting point found from the analysis was that the level of sequential patterns used by pharmaceutical laboratory projects was much higher than other types of projects. The proportion of sequential patterns was four times more frequent. A similar trend was also noticed in other light industrial projects: sequential pattern usage was higher than other patterns.

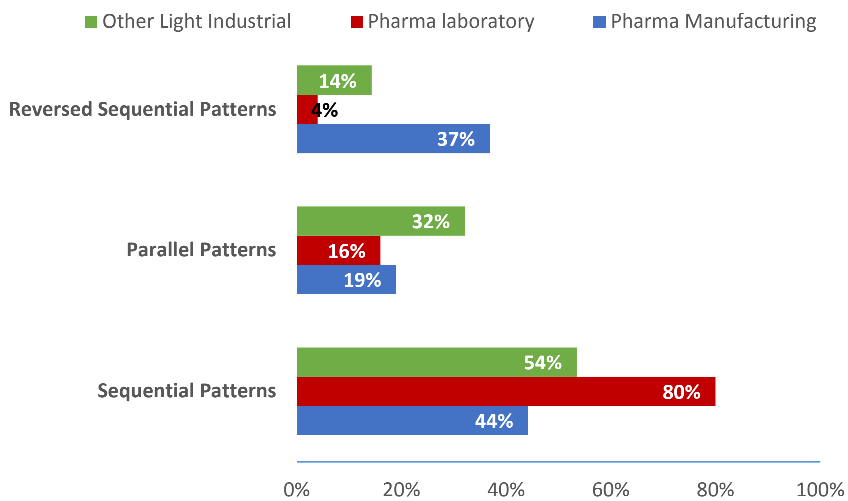


Figure 5.3 Patterns' Frequencies Used for the ENG-PRO by project types in the light industrial projects

Table 5.13 Frequency of the Pairwise Phase Patterns for Pharmaceutical Manufacturing Projects

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern1-Sequential arrangement of two phases w/o concurrency	95	65.3%	57.9%	2.1%	12.6%	3.2%	13.7%
Pattern2-Sequential arrangement of two phases w/ concurrency	95	31.6%	37.9%	42.1%	77.9%	72.6%	73.7%
Pattern3-Parallel arrangement of two phases w/ exact same stop	95	1.1%		1.1%		2.1%	3.2%
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	95			4.2%	1.1%	10.5%	8.4%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	95	1.1%	4.2%	10.5%	2.1%	3.2%	
Pattern6-Parallel arrangement of two phases with exact same start and stop	95	1.1%		1.1%			
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	95			2.1%			
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	95			27.4%	6.3%	7.4%	1.1%
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	95			4.2%		1.1%	
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	95			4.2%			
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	95			1.1%			

Table 5.14 Frequency of the Pairwise Phase Patterns for Pharmaceutical Laboratory Projects

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern1-Sequential arrangement of two phases w/o concurrency	25	76.0%	84.0%	20.0%	20.0%	4.0%	8.0%
Pattern2-Sequential arrangement of two phases w/ concurrency	25	20.0%	16.0%	60.0%	80.0%	68.0%	64.0%
Pattern3-Parallel arrangement of two phases w/ exact same stop	25			4.0%			28.0%
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	25	4.0%					
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	25			8.0%		12.0%	
Pattern6-Parallel arrangement of two phases with exact same start and stop	25						

Table 5.14 Frequency of the Pairwise Phase Patterns for Pharmaceutical Laboratory Projects (Continued)

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	25			4.0%			
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	25			4.0%		16.0%	
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	25						
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	25						
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	25						

Table 5.15 Frequency of the Pairwise Phase Patterns for Other Light Industrial Projects

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern1-Sequential arrangement of two phases w/o concurrency	28	53.6%	57.1%	7.1%	21.4%	10.7%	14.3%
Pattern2-Sequential arrangement of two phases w/ concurrency	28	42.9%	35.7%	46.4%	71.4%	78.6%	53.6%
Pattern3-Parallel arrangement of two phases w/ exact same stop	28						14.3%
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	28			10.7%			14.3%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	28	3.6%	7.1%	10.7%	3.6%	3.6%	
Pattern6-Parallel arrangement of two phases with exact same start and stop	28			7.1%			3.6%
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	28			3.6%			
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	28			10.7%	3.6%	7.1%	
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	28						
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	28			3.6%			
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	28						

5.3.3.2 Project Nature

Tables 5.16 through 5.18 present the frequency of patterns observed by project nature. More than 64% of the projects employed pattern 1. It was the most commonly used pattern for FEP-ENG. More than 58% of projects utilized pattern 1 for FEP-PRO. More than 64% of the projects used pattern 2 for ENG-CON and PRO-CON. In ENG-PRO, additions and grass roots projects employed the sequential patterns more than half of the time and only modernization projects utilized the reversed sequential patterns more than 30% of the time. It was also noticed that 10% of the grass roots projects and 4.2% of the addition projects experienced an early start of the construction before the engineering phase began. In addition, 8.5% of grass roots projects, 6.3% of addition projects, and 5.7% of modernization projects experienced late completion of the procurement phase, ending after the construction phase finished.

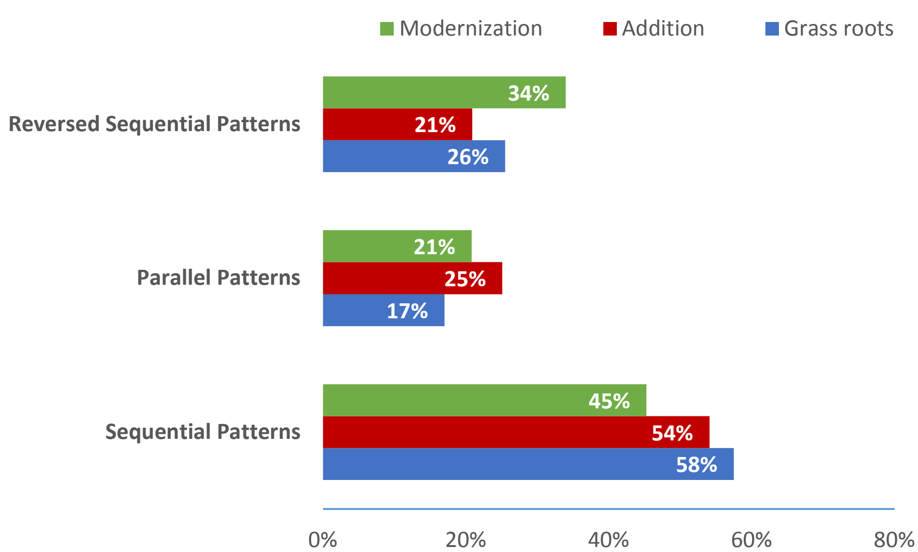


Figure 5.4 Patterns' Frequencies Used for the ENG-PRO by Project Nature

Table 5.16 Frequency of the Pairwise Phase Patterns for Grass Roots Projects

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern1-Sequential arrangement of two phases w/o concurrency	47	66.0%	61.7%	4.3%	6.4%		10.6%
Pattern2-Sequential arrangement of two phases w/ concurrency	47	31.9%	34.0%	53.2%	83.0%	78.7%	78.7%
Pattern3-Parallel arrangement of two phases w/ exact same stop	47			2.1%			8.5%
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	47			4.3%		8.5%	2.1%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	47		4.3%	8.5%		2.1%	
Pattern6-Parallel arrangement of two phases with exact same start and stop	47	2.1%					
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	47			2.1%			
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	47			21.3%	10.6%	10.6%	
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	47			2.1%			
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	47						
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	47			2.1%			

Table 5.17 Frequency of the Pairwise Phase Patterns for Addition Projects

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern1-Sequential arrangement of two phases w/o concurrency	48	64.6%	66.7%	8.3%	12.5%	6.3%	18.8%
Pattern2-Sequential arrangement of two phases w/ concurrency	48	33.3%	31.3%	45.8%	79.2%	64.6%	60.4%
Pattern3-Parallel arrangement of two phases w/ exact same stop	48	2.1%				4.2%	10.4%
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	48			4.2%	2.1%	6.3%	8.3%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	48		2.1%	12.5%	2.1%	4.2%	
Pattern6-Parallel arrangement of two phases with exact same start and stop	48			4.2%			

Table 5.17 Frequency of the Pairwise Phase Patterns for Addition Projects (Continued)

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	48			4.2%			
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	48			18.8%	4.2%	12.5%	2.1%
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	48					2.1%	
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	48			2.1%			
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	48						

Table 5.18 Frequency of the Pairwise Phase Patterns for Modernization Projects

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern1-Sequential arrangement of two phases w/o concurrency	53	64.2%	58.5%	5.7%	26.4%	7.5%	9.4%
Pattern2-Sequential arrangement of two phases w/ concurrency	53	30.2%	35.8%	39.6%	69.8%	75.5%	66.0%
Pattern3-Parallel arrangement of two phases w/ exact same stop	53			1.9%			9.4%
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	53	1.9%		5.7%		5.7%	13.2%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	53	3.8%	5.7%	9.4%	3.8%	7.5%	
Pattern6-Parallel arrangement of two phases with exact same start and stop	53			1.9%			1.9%
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	53			1.9%			
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	53			20.8%		3.8%	
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	53			5.7%			
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	53			7.5%			
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	53						

5.3.2.3 Project Size

Tables 5.19 through 5.21 present the frequency of patterns by project size. It was found that project size does not affect the different use of patterns. More than 63.8% of projects employed pattern 1, which was the most commonly used pattern for FEP-ENG. More than 57.4% of projects utilized pattern 1 for FEP-PRO. Slightly more than 68% of projects used pattern 2 for ENG-CON and PRO-CON. Furthermore, as found in project nature, relatively high use of sequential patterns was found with projects in all cost categories. Among other cost categories, the projects in the cost range between $50MM-$100MM indicated the highest use (60%) of sequential patterns, whereas parallel patterns experienced the lowest use (15%). It was noticed that 2.1% of the projects in the cost range between $50MM-$100MM and 12.8% of the projects in $100MM-$500MM experienced the early start of construction before the engineering phase had begun. In addition, 5.6% of the projects in the cost range between $10MM-$50MM, 4.3% of the projects in $50MM-$100MM, and 12.6% of the projects in $100MM-$500MM experienced a late completion of the procurement phase, finishing after the construction phase had ended.

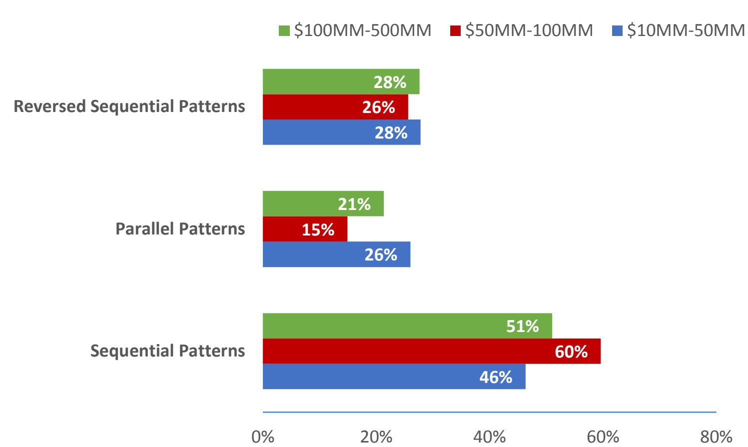


Figure 5.5 Patterns' Frequencies Used for the ENG-PRO by Project Size

Table 5.19 Frequency of the Pairwise Phase Patterns for Projects in $10MM-$50MM

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern1-Sequential arrangement of two phases w/o concurrency	54	66.7%	63.0%	7.4%	22.2%	5.6%	16.7%
Pattern2-Sequential arrangement of two phases w/ concurrency	54	27.8%	33.3%	38.9%	74.1%	68.5%	64.8%
Pattern3-Parallel arrangement of two phases w/ exact same stop	54			1.9%		1.9%	13.0%
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	54	1.9%		5.6%		5.6%	3.7%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	54	3.7%	3.7%	11.1%	3.7%	9.3%	
Pattern6-Parallel arrangement of two phases with exact same start and stop	54			3.7%			1.9%
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	54			3.7%			
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	54			22.2%		9.3%	
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	54			1.9%			
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	54			3.7%			
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	54						

Table 5.20 Frequency of the Pairwise Phase Patterns for Projects in $50MM-$100MM

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern1-Sequential arrangement of two phases w/o concurrency	47	63.8%	66.0%	8.5%	17.0%	4.3%	10.6%
Pattern2-Sequential arrangement of two phases w/ concurrency	47	36.2%	29.8%	51.1%	76.6%	76.6%	70.2%
Pattern3-Parallel arrangement of two phases w/ exact same stop	47			2.1%		2.1%	6.4%
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	47				2.1%	4.3%	12.8%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	47		4.3%	6.4%	2.1%		
Pattern6-Parallel arrangement of two phases with exact same start and stop	47			2.1%			

Table 5.20 Frequency of the Pairwise Phase Patterns for Projects in $50MM-$100MM (Continued)

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	47			4.3%			
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	47			21.3%	2.1%	12.8%	
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	47						
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	47			4.3%			
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	47						

Table 5.21 Frequency of the Pairwise Phase Patterns for Project in $100MM-$500MM

Description of Pattern	Sample Size	FEP-ENG	FEP-PRO	ENG-PRO	ENG-CON	PRO-CON	CON-STARTUP
Pattern1-Sequential arrangement of two phases w/o concurrency	47	63.8%	57.4%	2.1%	6.4%	4.3%	10.6%
Pattern2-Sequential arrangement of two phases w/ concurrency	47	31.9%	38.3%	48.9%	80.9%	74.5%	70.2%
Pattern3-Parallel arrangement of two phases w/ exact same stop	47	2.1%					8.5%
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	47			8.5%		10.6%	8.5%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	47		4.3%	12.8%		4.3%	
Pattern6-Parallel arrangement of two phases with exact same start and stop	47	2.1%					
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	47						
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	47			17.0%	12.8%	4.3%	2.1%
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	47			6.4%		2.1%	
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	47			2.1%			
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	47			2.1%			

5.4 IDENTIFICATION OF THE TRIPLE-WISE PHASE ARRANGEMENT

Table 5.22 presents the fifteen top patterns identified in the three combinations of triple-wise phases, which includes: front-end planning, engineering, procurement phases (FEP); engineering, procurement, construction phases (EPC); and procurement, construction, and startup phases (PCS). Due to the similarity of some patterns, the table groups the patterns that share similar arrangement in the first two phases. As shown, each pattern includes the combination of patterns identified in the pairwise phase arrangements along with its rank of frequency in the three combinations of phases. Each number in the combination of patterns describes how the two phases are arranged. For example, if a 1-1-2 were chosen for FEP, it would indicate that: 1) the first two combinations of phases are arranged sequentially without concurrency in the pairwise phase arrangement; and 2) the last combination of phases is arranged sequentially with concurrency. Furthermore, the order of 1-1-2 for FEP would mean this sequence of phase combinations: front-end planning and engineering; front-end planning and procurement; and engineering and procurement, in that order. The blue arrows define the relationship between the first two phases and the red arrows indicate the relationship between the last two phases. The green arrows show the relationship between the first and last phases. In addition, the rank of each pattern's frequency, next to the combination of patterns is the result of all 1,065 observed cases, where the 1,065 cases are equal to the total number of projects collected (355) multiplied by the three combinations of triple-wise phases. As a result, the most frequently used pattern across the three combinations of triple-wise phases was pattern 9, a sequential phase arrangement with concurrency on all three phases, followed by pattern 6, a sequential phase arrangement of the first two phases with concurrency and a sequential phase arrangement of the last two phases without concurrency. The corresponding frequencies of the two were 13% (135 cases) and 11% (119 cases) respectively. In total, eighty-seven various patterns were identified, but seventy-two patterns (83%) have less than 15 cases. The 2-2-4 arrangement, the last in the top 15 patterns, was employed in 20 cases and was used as the cutoff point.

Table 5.22 Descriptions of Patterns and Their Graphical Illustration

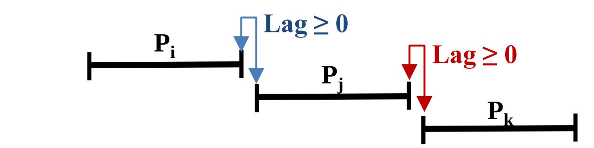
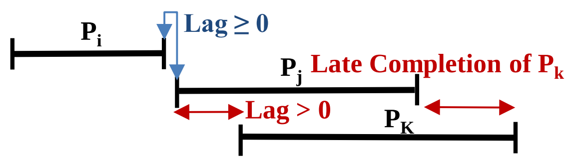
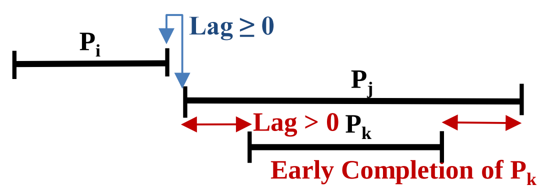
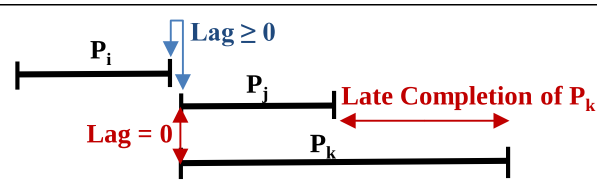
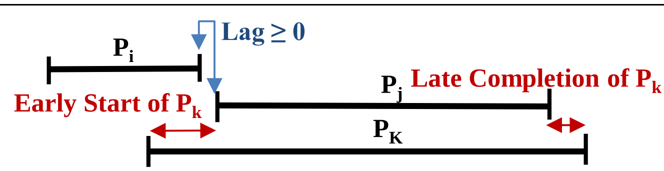
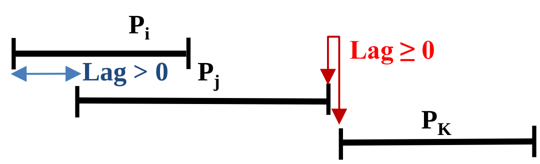
<table>
<tr><td>Description of pattern
(combination of patterns, rank)</td><td>Phase Arrangement Patterns includes:
(P_i :the first phase, P_j: the interim phase, and P_k: the last phase</td></tr>
<tr><td>Pattern 1 (1-1-1, 8):
Sequential arrangement w/o concurrency on Pi-Pj, on Pi-Pk, and on Pj-Pk</td><td>
</td></tr>
<tr><td>Pattern 2 (1-1-2, 4):
Sequential arrangement w/o concurrency on Pi-Pj and on Pi-Pk; Sequential arrangement w/ concurrency on Pj and Pk</td><td>
</td></tr>
<tr><td>Pattern 3 (1-1-4, 13):
Sequential arrangement w/o concurrency on Pi-Pj and on Pi-Pk; Parallel arrangement on Pj and Pk</td><td>
</td></tr>
<tr><td>Pattern 4 (1-1-5, 9):
Sequential arrangement w/o concurrency on Pi-Pj and on Pi-Pk; Parallel arrangement on Pj-Pk with the same start</td><td>
</td></tr>
<tr><td>Pattern 5 (1-2-8, 10):
Sequential arrangement w/o concurrency on Pi-Pj; Sequential arragement w/ concurrency on Pi-Pk; Reversed sequential arrangement on Pj-Pk</td><td>
</td></tr>
<tr><td>Pattern 6 (2-1-1, 2):
Sequential arrangement w/ concurrency on Pi-Pj; Sequential arrangement w/o concurrency on Pi-Pk; Sequential arrangement w/o concurrency on Pj-Pk</td><td>
</td></tr>
</table>

Table 5.22 Descriptions of Patterns and Their Graphical Illustration (Continued)

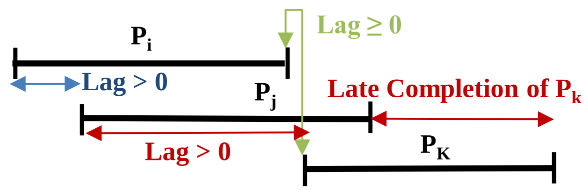
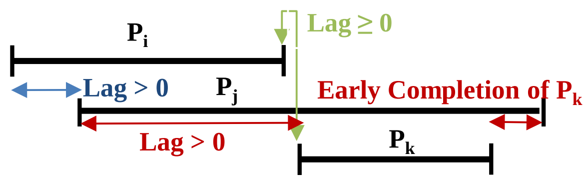
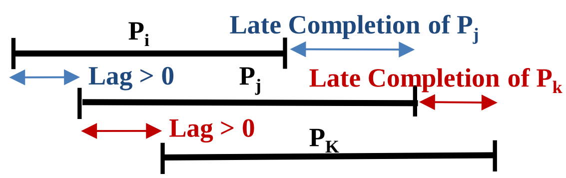
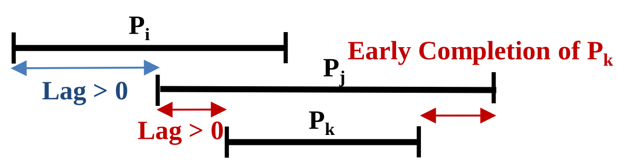
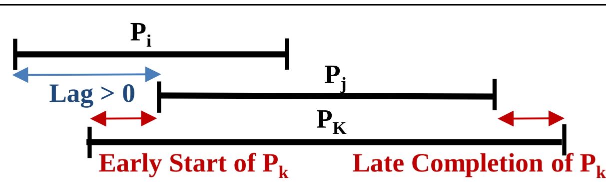
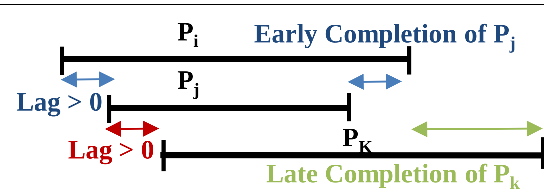
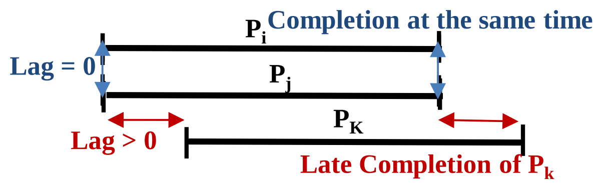
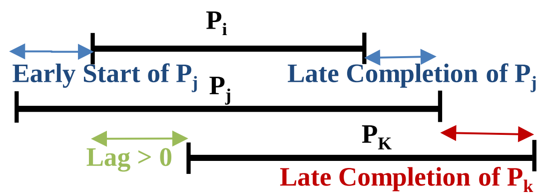
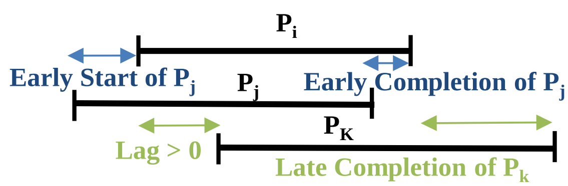
Description of pattern (combination of patterns, rank)	Phase Arrangement Patterns includes: (P_i :the first phase, P_j: the interim phase, and P_k: the last phase
Pattern 7 (2-1-2, 3): Sequential arrangement w/ concurrency on Pi-Pj; Sequential arrangement w/o concurrency on Pi-Pk; Sequential arrangement w/ concurrency on Pj-Pk	
Pattern 8 (2-1-4, 12): Sequential arrangement w/ concurrency on Pi-Pj; Sequential arrangement w/o concurrency on Pi-Pk; Parallel arrangement on Pj-Pk w/ early completion of Pk	
Pattern 9(2-2-2, 1): Sequential arrangement w/ concurrency on Pi-Pj; Sequential arrangement w/ concurrency on Pi-Pk; Sequential arrangement on Pj-Pk	
Pattern 10 (2-2-4, 15): Sequential arrangement w/ concurrency on Pi-Pj; Sequential arrangement w/ concurrency on Pi-Pk; Parallel arrangement on Pj-Pk w/ early completion of Pk	
Pattern 11 (2-2-8, 7): Sequential arrangement w/ concurrency on Pi-Pj; Sequential arrangement w/ concurrency on Pi-Pk; Reversed sequential arrangement on Pj-Pk	
Pattern 12 (4-2-2, 6): Parallel arrangement on Pi-Pj w/ early completion of Pj; Sequential arrangement w/ concurrency on Pi-Pk; Sequential arrangement on Pj-Pk	

Table 5.22 Descriptions of Patterns and Their Graphical Illustration (Continued)

Description of pattern (combination of patterns, rank)	Phase Arrangement Patterns includes: (P_i :the first phase, P_j: the interim phase, and P_k: the last phase
Pattern 13 (5-2-2, 11): Parallel arrangement on Pi-Pj w/ the same start and completion; Sequential arrangement w/ concurrency on Pi-Pk; Sequential arrangement w/ concurrency on Pj-Pk	
Pattern 14 (8-2-2, 5): Reversed sequential arrangement on Pi-Pj w/ late completion of Pj; Sequential arrangement w/ concurrency on Pi-Pk; Sequential arrangement w/ concurrency on Pj-Pk	
Pattern 15 (10-2-2, 14): Reversed sequential arrangement on Pi-Pj w/ early completion of Pj; Sequential arrangement w/ concurrency on Pi-Pk; Sequential arrangement w/ concurrency on Pj-Pk	

5.5 Frequencies of the Triple-wise Phase Arrangement

5.5.1 Industrial Projects

Table 5.23 illustrates the frequencies of the triple-wise phase patterns for industrial projects with color coding. The green-shaded boxes indicate patterns frequently employed and white, or unshaded boxes, indicate patterns rarely used. Frequency was represented as a percent value of the number of projects that used the pattern out of a given sample size. Each pattern was grouped by similar characteristics. For example, group 1 represents patterns 1 through 5 in which the sequential phase arrangement without concurrency between the first and second phases was found. The subtotal of each group is represented as a percent value and was color coded by use in each pattern to present its intensity. The total percent values at the bottom of the table indicate the observed portion of the identified patterns in each triple-wise pattern.

As shown in the table, more than 70% of the projects on average utilized the top fifteen patterns. A total of 46.8% of the projects employed the sequential phase arrangement without concurrency between the front-end planning and engineering phases in the FEP (the front-end planning-engineering-procurement phases) combination. The second highest portion, 23.7%, was revealed as group 2 in which the front end planning and engineering phases had some extent of concurrency. Specifically, 22.3% of the projects used pattern 2, the sequential phase arrangement between the first and second phases and the first and third phases without concurrency and the sequential phase arrangement between the second and last phases with concurrency, in FEP (the front-end planning-engineering-procurement phases) combination, followed by 7.3% with pattern 4 and pattern 7. An average of 36.1% of the projects used the patterns categorized as other, the highest portion in the EPC combination. Interestingly, the sum of projects with pattern 13 and pattern 15 for the EPC combination accounted for 27.3%, meaning that 27.3% of industrial projects had their procurement phase start at the same time as the engineering phase started or sooner. A total of 22.0% of the projects used pattern 9, the most frequently observed result, in which all three phases were arranged sequentially with concurrency. In the PCS combination, group 2 illustrates that the sequential arrangement with concurrency between the procurement and construction phases shows the highest frequency of use (71%). Pattern 6, the sequential arrangement with concurrency between the procurement and construction phases and the sequential arrangement without concurrency between the procurement and startup phases and between the construction and startup phases, accounted for 31.5%, followed by 20.8% with pattern 7.

Table 5.23 Frequency of Triple-wise Phase Arrangement for Industrial Projects

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	355	3.9%	1.1%	4.8%
2	1-1-2		355	22.3%	1.1%	1.4%
3	1-1-4		355	6.2%	0.3%	0.3%
4	1-1-5		355	7.3%	0.6%	
5	1-2-8		355	7.0%	0.8%	
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	355	0.3%	1.7%	31.5%
7	2-1-2		355	7.3%	5.1%	20.8%
8	2-1-4		355	2.0%		5.1%
9	2-2-2		355	4.8%	22.0%	11.3%
10	2-2-4		355	2.8%	0.6%	2.3%
11	2-2-8		355	6.5%	3.7%	
12	4-2-2	Group 3: Other	355	0.8%	8.7%	2.0%
13	5-2-2		355		7.6%	0.3%
14	8-2-2		355		13.5%	0.8%
15	10-2-2		355		6.2%	
Subtotal of the Group 1				46.8%	3.9%	6.5%
Subtotal of the Group 2				23.7%	33.0%	71.0%
Subtotal of the Group 3				0.8%	36.1%	3.1%
Total				**71.3%**	**73.0%**	**80.6%**

Tables 5.24 and 5.25 present the frequencies of triple-wise phase arrangements for heavy industrial projects and light industrial projects respectively. A comparative view shows that a remarkable difference between heavy and light industrial projects exist for the EPC combination: 42% of heavy industrial projects used patterns defined as other. The sum of percent values for patterns 13 through 15 accounted for 30%, meaning that 30% of heavy industrial projects had the procurement phase starting at the same time as the engineering phase or the procurement started even earlier than the engineering phase started. On the other hand, 41.2% of light industrial projects employed group 2, the sequential phase arrangement with concurrency between engineering and procurement. Individual pattern-wise, the highest frequency was observed in pattern 9 in both heavy and light industrial projects, 16.4% and 29.7% respectively. The second highest frequency was

found in pattern 14 where the procurement phase started before the engineering started in heavy and light industrial projects, at 14% and 12.8% respectively. Another difference was found in the PCS combination with 47.8 % of heavy industrial projects employing pattern 6, whereas only 8.8 % of light industrial projects used it. A total of 14% of heavy industrial projects used pattern 7, the second highest frequency in PCS combination, whereas 30.4% of light industrial projects utilized it. The difference between the two patterns is how the construction and startup phases are arranged. That is, with the highest frequency, heavy industrial projects tended not to have concurrency between the two phases, whereas slightly more than 30% of the light industrial projects allowed some extent of concurrency.

Table 5.24 Frequency of Triple-wise Phase Arrangement for Heavy Industrial Projects

Pattern	**Combination of Patterns**	**Group of Patterns**	**Sample Size**	**FEP (FEP-ENG-PRO)**	**EPC (ENG-PRO-CON)**	**PCS (PRO-CON-STA)**
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	207	2.9%	1.0%	8.2%
2	1-1-2		207	17.4%	1.4%	0.5%
3	1-1-4		207	9.7%		0.5%
4	1-1-5		207	7.7%		
5	1-2-8		207	5.8%	0.5%	
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	207		2.4%	47.8%
7	2-1-2		207	5.8%	4.8%	14.0%
8	2-1-4		207	2.9%		6.3%
9	2-2-2		207	3.4%	16.4%	5.3%
10	2-2-4		207	3.4%		1.4%
11	2-2-8		207	6.8%	3.4%	
12	4-2-2	Group 3: Other	207	1.0%	12.1%	
13	5-2-2		207		6.8%	
14	8-2-2		207		14.0%	
15	10-2-2		207		9.2%	
Subtotal of the Group 1				43.5%	2.9%	9.2%
Subtotal of the Group 2				22.2%	27.1%	74.9%
Subtotal of the Group 3				1.0%	42.0%	0.0%
Total				**66.7%**	**72.0%**	**84.1%**

Table 5.25 Frequency of Triple-wise Phase Arrangement for Light Industrial Projects

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	148	5.4%	1.4%	
2	1-1-2		148	29.1%	0.7%	2.7%
3	1-1-4		148	1.4%	0.7%	
4	1-1-5		148	6.8%	1.4%	
5	1-2-8		148	8.8%	1.4%	
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	148	0.7%	0.7%	8.8%
7	2-1-2		148	9.5%	5.4%	30.4%
8	2-1-4		148	0.7%		3.4%
9	2-2-2		148	6.8%	29.7%	19.6%
10	2-2-4		148	2.0%	1.4%	3.4%
11	2-2-8		148	6.1%	4.1%	
12	4-2-2	Group 3: Other	148	0.7%	4.1%	4.7%
13	5-2-2		148		8.8%	0.7%
14	8-2-2		148		12.8%	2.0%
15	10-2-2		148		2.0%	
Subtotal of the Group 1				51.4%	5.4%	2.7%
Subtotal of the Group 2				25.7%	41.2%	65.5%
Subtotal of the Group 3				0.7%	27.7%	7.4%
Total				**77.7%**	**74.3%**	**75.7%**

5.5.2 Heavy Industrial Projects

5.5.2.1 Process and Non-process projects

Tables 5.26 and 5.27 present the frequencies of triple-wise phase arrangements for process projects and for non-process projects. A remarkable difference was found between the two types of projects with the EPC combination: 22.6% of process projects tended to employ patterns in group 2, whereas more than 41% of non-process projects used them. Similarly, the sequential arrangements between front-end planning and engineering without concurrency, categorized in group 1 in process projects accounted for 39.6%, but its use in non-process projects was 56.3%. It was observed that non-process projects tended not to have concurrency between front-end planning and engineering, but those projects employed higher use of sequential arrangement with concurrency between engineering and procurement. Furthermore, 25.8% of the projects conducted an early procurement phase starting before the engineering phase started in processing projects based on the use of patterns 14 and 15. Non-process projects showed a 9%p lower frequency of early procurement.

Individual pattern-wise, non-process projects used pattern 2 at 29.2% in the FEP combination, whereas only 13.8% of the projects used it in process projects. None of the projects used pattern 1 or pattern 2 in non-process projects in the EPC combination, but slightly more than 3% of the projects used them in process projects. In the PCS combination, the sequential arrangements without concurrency, patterns 1 through 5, show much higher usage in non-process projects (14.6%) than in process projects (6.3%).

Table 5.26 Frequency of Triple-wise Phase Arrangement for Process Projects

Pattern	**Combination of Patterns**	**Group of Patterns**	**Sample Size**	**FEP (FEP-ENG-PRO)**	**EPC (ENG-PRO-CON)**	**PCS (PRO-CON-STA)**
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	159	3.8%	1.3%	6.3%
2	1-1-2		159	13.8%	1.9%	0.6%
3	1-1-4		159	10.1%		0.6%
4	1-1-5		159	6.3%		
5	1-2-8		159	5.7%	0.6%	
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	159		0.6%	47.8%
7	2-1-2		159	6.3%	3.1%	13.2%
8	2-1-4		159	3.1%		7.5%
9	2-2-2		159	2.5%	15.7%	5.0%
10	2-2-4		159	3.1%		1.3%
11	2-2-8		159	6.3%	3.1%	
12	4-2-2	Group 3: Other	159	0.6%	11.9%	
13	5-2-2		159		6.3%	
14	8-2-2		159		14.5%	
15	10-2-2		159		11.3%	
Subtotal of the Group 1				39.6%	3.8%	7.5%
Subtotal of the Group 2				21.4%	22.6%	74.8%
Subtotal of the Group 3				0.6%	44.0%	0.0%
Total				**61.6%**	**70.4%**	**82.4%**

Table 5.27 Frequency of Triple-wise Phase Arrangement for Non-process Projects

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	48			14.6%
2	1-1-2		48	29.2%		
3	1-1-4		48	8.3%		
4	1-1-5		48	12.5%		
5	1-2-8		48	6.3%		
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	48		8.3%	47.9%
7	2-1-2		48	4.2%	10.4%	16.7%
8	2-1-4		48	2.1%		2.1%
9	2-2-2		48	6.3%	18.8%	6.3%
10	2-2-4		48	4.2%		2.1%
11	2-2-8		48	8.3%	4.2%	
12	4-2-2	Group 3: Other	48	2.1%	12.5%	
13	5-2-2		48		8.3%	
14	8-2-2		48		12.5%	
15	10-2-2		48		2.1%	
Subtotal of the Group 1				56.3%	0.0%	14.6%
Subtotal of the Group 2				25.0%	41.7%	75.0%
Subtotal of the Group 3				2.1%	35.4%	0.0%
Total				**83.3%**	**77.1%**	**89.6%**

5.5.2.2 Project Nature

Tables 5.28 through 5.30 illustrate the frequencies of triple-wise phase arrangements for projects with various natures. Overall distribution of pattern frequencies do not show significant differences in this category. It was also observed that each pattern's frequency was not distinctively different across project natures. Group 1 showed the highest use across different project natures, where patterns are combined with sequential arrangement without concurrency between the front-end planning and engineering phases. Patterns in group 3 were found to be the highest in the EPC combination. On the other hand, patterns in group 2 showed the highest use in the PCS combination. Mainly, pattern 6 contributed to the highest use with more than 40% projects in each category. Pattern 6 entails the sequential arrangement with concurrency between the procurement and construction phases and the sequential arrangement without concurrency between the procurement and startup phases and between the construction and startup phases.

Table 5.28 Frequency of Triple-wise Phase Arrangement for Grass Roots Projects

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	54	3.7%	1.9%	11.1%
2	1-1-2		54	16.7%		
3	1-1-4		54	5.6%		
4	1-1-5		54	3.7%		
5	1-2-8		54	11.1%	1.9%	
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	54			42.6%
7	2-1-2		54	7.4%	1.9%	25.9%
8	2-1-4		54			1.9%
9	2-2-2		54	5.6%	22.2%	5.6%
10	2-2-4		54	3.7%		
11	2-2-8		54	9.3%	5.6%	
12	4-2-2	Group 3: Other	54		5.6%	
13	5-2-2		54		3.7%	
14	8-2-2		54		20.4%	
15	10-2-2		54		7.4%	
Subtotal of the Group 1				40.7%	3.7%	11.1%
Subtotal of the Group 2				25.9%	29.6%	75.9%
Subtotal of the Group 3				0.0%	37.0%	0.0%
Total				**66.7%**	**70.4%**	**87.0%**

Table 5.29 Frequency of Triple-wise Phase Arrangement for Addition Projects

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	74	2.7%	1.4%	4.1%
2	1-1-2		74	16.2%	1.4%	1.4%
3	1-1-4		74	14.9%		1.4%
4	1-1-5		74	9.5%		
5	1-2-8		74	2.7%		

Table 5.29 Frequency of Triple-wise Phase Arrangement for Addition Projects (Continued)

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	74		1.4%	50.0%
7	2-1-2		74	4.1%	6.8%	13.5%
8	2-1-4		74	5.4%		4.1%
9	2-2-2		74	4.1%	16.2%	4.1%
10	2-2-4		74	1.4%		4.1%
11	2-2-8		74	5.4%	2.7%	
12	4-2-2	Group 3: Other	74	2.7%	18.9%	
13	5-2-2		74		6.8%	
14	8-2-2		74		12.2%	
15	10-2-2		74		6.8%	
Subtotal of the Group 1				45.9%	2.7%	6.8%
Subtotal of the Group 2				20.3%	27.0%	75.7%
Subtotal of the Group 3				2.7%	44.6%	0.0%
Total				**68.9%**	**74.3%**	**82.4%**

Table 5.30 Frequency of Triple-wise Phase Arrangement for Modernization Projects

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	79	2.5%		10.1%
2	1-1-2		79	19.0%	2.5%	
3	1-1-4		79	7.6%		
4	1-1-5		79	8.9%		
5	1-2-8		79	5.1%		
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	79		5.1%	49.4%
7	2-1-2		79	6.3%	5.1%	6.3%
8	2-1-4		79	2.5%		11.4%
9	2-2-2		79	1.3%	12.7%	6.3%
10	2-2-4		79	5.1%		
11	2-2-8		79	6.3%	2.5%	
12	4-2-2	Group 3: Other	79		10.1%	
13	5-2-2		79		8.9%	
14	8-2-2		79		11.4%	
15	10-2-2		79		12.7%	
Subtotal of the Group 1				43.0%	2.5%	10.1%
Subtotal of the Group 2				21.5%	25.3%	73.4%
Subtotal of the Group 3				0.0%	43.0%	0.0%
Total				**64.6%**	**70.9%**	**83.5%**

5.5.2.3 Project Size

Tables 5.31 through 5.33 show the frequencies of triple-wise phase arrangements for projects with a given project size. It was found that a similar distribution and frequencies of patterns were presented as shown in project nature. Overall distribution of the patterns' frequency did not show significant differences for different project size. In addition, each pattern's frequency was not distinctively different across project sizes. Group 1, combined with patterns employing the sequential arrangement without concurrency between front-end planning and engineering showed the highest use across different project sizes. Patterns in group 3 showed the highest employment in the EPC combination. Projects costing \$50MM-\$100MM present the highest use of patterns in group 3. Patterns in group 2 showed the highest use in the PCS combination. Pattern 6 had the highest use, and projects costing \$50MM-\$100MM show the highest use at 64.7%.

Table 5.31 Frequency of Triple-wise Phase Arrangement for Project's Cost in \$10MM-\$50MM

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	104	4.8%	1.9%	7.7%
2	1-1-2		104	21.2%	2.9%	
3	1-1-4		104	8.7%		1.0%
4	1-1-5		104	6.7%		
5	1-2-8		104	4.8%		
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	104		4.8%	41.3%
7	2-1-2		104	4.8%	7.7%	12.5%
8	2-1-4		104	3.8%		6.7%
9	2-2-2		104	3.8%	15.4%	3.8%
10	2-2-4		104	4.8%		1.0%
11	2-2-8		104	2.9%	3.8%	
12	4-2-2	Group 3: Other	104	1.9%	10.6%	
13	5-2-2		104		4.8%	
14	8-2-2		104		8.7%	
15	10-2-2		104		10.6%	

Table 5.31 Frequency of Triple-wise Phase Arrangement for Project's Cost in $10MM-$50MM (Continued)

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
Subtotal of the Group 1				46.2%	4.8%	8.7%
Subtotal of the Group 2				20.2%	31.7%	65.4%
Subtotal of the Group 3				1.9%	34.6%	0.0%
Total				**68.3%**	**71.2%**	**74.0%**

Table 5.32 Frequency of Triple-wise Phase Arrangement for Project's Cost in $50MM-$100MM

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	34			0.0%
2	1-1-2		34	5.9%		0.0%
3	1-1-4		34	14.7%		
4	1-1-5		34	11.8%		
5	1-2-8		34	2.9%		
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	34			64.7%
7	2-1-2		34	11.8%		14.7%
8	2-1-4		34	2.9%		2.9%
9	2-2-2		34	2.9%	11.8%	5.9%
10	2-2-4		34			
11	2-2-8		34	11.8%	5.9%	
12	4-2-2	Group 3: Other	34		17.6%	
13	5-2-2		34		14.7%	
14	8-2-2		34		14.7%	
15	10-2-2		34		8.8%	
Subtotal of the Group 1				35.3%	0.0%	0.0%
Subtotal of the Group 2				29.4%	17.6%	88.2%
Subtotal of the Group 3				0.0%	55.9%	0.0%
Total				**64.7%**	**73.5%**	**88.2%**

Table 5.33 Frequency of Triple-wise Phase Arrangement for Project's Cost in $100MM-$500MM

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	69	1.4%		10.1%
2	1-1-2		69	17.4%		
3	1-1-4		69	8.7%		
4	1-1-5		69	7.2%		
5	1-2-8		69	8.7%	1.4%	
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	69			39.1%
7	2-1-2		69	4.3%	2.9%	15.9%
8	2-1-4		69	1.4%		7.2%
9	2-2-2		69	2.9%	20.3%	5.8%
10	2-2-4		69	2.9%		2.9%
11	2-2-8		69	10.1%	1.4%	
12	4-2-2	Group 3: Other	69		11.6%	
13	5-2-2		69		5.8%	
14	8-2-2		69		21.7%	
15	10-2-2		69		7.2%	
Subtotal of the Group 1				43.5%	1.4%	10.1%
Subtotal of the Group 2				21.7%	24.6%	71.0%
Subtotal of the Group 3				0.0%	46.4%	0.0%
Total				**65.2%**	**72.5%**	**81.2%**

5.5.3 Light Industrial Projects

5.5.3.1 Pharmaceutical Manufacturing, Laboratory, and Other Light Industrial Projects

Tables 5.34, 5.35, and 5.36 present the frequencies of triple-wise phase arrangements for light industrial projects and those projects were divided by project types. Overall distribution of patterns' frequency amongst the three project types showed that there is no distinctive difference across the three combinations of triple-wise phase arrangements. However, each pattern's frequency was noticeably different across project types. In the FEP combination, patterns in group 1 showed the highest use in all project types. Specifically, pharmaceutical laboratory projects had the highest use (72%). Patterns in group 2 provided the highest employment in all project types in the EPC combination. Interestingly, 18.9% of pharmaceutical manufacturing projects conducted an early procurement phase before the engineering phase started, based on the frequencies of patterns 14 and 15. That is the highest proportion, compared to 4% of pharmaceutical laboratory projects and 10.7% of other light industrial projects. Furthermore, 20% of the pharmaceutical laboratory projects employed patterns in group 1 that is the highest proportion of project use compared to 2.1% of pharmaceutical manufacturing projects and 3.6% of other light industrial projects. It was also observed that pharmaceutical laboratory projects show relatively less use (48%) of the sequential phase arrangements with concurrency on the procurement and construction phases (group 2), than pharmaceutical manufacturing projects (69.5%) and other light industrial projects (67.9%).

Pattern 2 and pattern 9 showed the highest use in FEP and EPC combinations across project types. Pattern 7 had the highest use in the PCS combination, followed by pattern 9 across project types. This means that the most frequently used arrangement between construction and startup for more than 40% of the projects was the sequential arrangement with concurrency. That is, more than 40% of the projects experienced an early startup phase start before the construction phase was complete. This supports the remarkable difference between heavy and light industrial projects, where slightly more than 47% of the projects falls in pattern 6 with the sequential arrangement without concurrency between them.

Table 5.34 Frequency of Triple-wise Phase Arrangement for Pharmaceutical Manufacturing Projects

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	95	2.1%		
2	1-1-2		95	26.3%		2.1%
3	1-1-4		95	1.1%	1.1%	
4	1-1-5		95	8.4%		
5	1-2-8		95	11.6%	1.1%	
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	95		1.1%	7.4%
7	2-1-2		95	9.5%	6.3%	33.7%
8	2-1-4		95	1.1%		2.1%
9	2-2-2		95	6.3%	23.2%	22.1%
10	2-2-4		95	1.1%	2.1%	4.2%
11	2-2-8		95	9.5%	3.2%	
12	4-2-2	Group 3: Other	95		3.2%	7.4%
13	5-2-2		95		9.5%	1.1%
14	8-2-2		95		16.8%	2.1%
15	10-2-2		95		2.1%	
Subtotal of the Group 1				49.5%	2.1%	2.1%
Subtotal of the Group 2				27.4%	35.8%	69.5%
Subtotal of the Group 3				0.0%	31.6%	10.5%
Total				**76.8%**	**69.5%**	**82.1%**

Table 5.35 Frequency of Triple-wise Phase Arrangement for Pharmaceutical Laboratory Projects

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	25	16.0%	4.0%	
2	1-1-2		25	44.0%	4.0%	4.0%
3	1-1-4		25			
4	1-1-5		25	8.0%	8.0%	
5	1-2-8		25	4.0%	4.0%	
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	25	4.0%		8.0%
7	2-1-2		25	8.0%	4.0%	24.0%
8	2-1-4		25			
9	2-2-2		25	4.0%	40.0%	16.0%
10	2-2-4		25			
11	2-2-8		25		12.0%	
12	4-2-2	Group 3: Other	25	4.0%		
13	5-2-2		25		8.0%	
14	8-2-2		25		4.0%	4.0%
15	10-2-2		25			

Table 5.35 Frequency of Triple-wise Phase Arrangement for Pharmaceutical Laboratory Projects (Continued)

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
Subtotal of the Group 1				72.0%	20.0%	4.0%
Subtotal of the Group 2				16.0%	56.0%	48.0%
Subtotal of the Group 3				4.0%	12.0%	4.0%
Total				**92.0%**	**88.0%**	**56.0%**

Table 5.36 Frequency of Triple-wise Phase Arrangement for Other Light Industrial Projects

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	28	7.1%	3.6%	
2	1-1-2		28	25.0%		3.6%
3	1-1-4		28	3.6%		
4	1-1-5		28			
5	1-2-8		28	3.6%		
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	28			14.3%
7	2-1-2		28	10.7%	3.6%	25.0%
8	2-1-4		28			10.7%
9	2-2-2		28	10.7%	42.9%	14.3%
10	2-2-4		28	7.1%		3.6%
11	2-2-8		28			
12	4-2-2	Group 3: Other	28		10.7%	
13	5-2-2		28		7.1%	
14	8-2-2		28		7.1%	
15	10-2-2		28		3.6%	
Subtotal of the Group 1				39.3%	3.6%	3.6%
Subtotal of the Group 2				28.6%	46.4%	67.9%
Subtotal of the Group 3				0.0%	28.6%	0.0%
Total				**67.9%**	**78.6%**	**71.4%**

5.5.3.2 Project Nature

Tables 5.37 through 5.39 show the frequencies of triple-wise phase arrangements for light industrial projects for various project natures. Overall distribution of the patterns' frequency does not show significant difference amongst the projects in different natures. It was noticed that each pattern's frequency was not distinctively different across project types. Group 1, combined with patterns employing the sequential arrangement without concurrency between front-end planning and engineering, showed the highest use across different project natures. Patterns in group 2 showed the highest employment for EPC and PCS combinations. Pattern 7 had the highest use with more than 22% projects in each nature. Specifically, patterns 9 and 7 in pharmaceutical manufacturing projects showed the highest use with the EPC and PCS combinations respectively.

Table 5.37 Frequency of Triple-wise Phase Arrangement for Grass Roots Projects

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	47	4.3%		
2	1-1-2		47	36.2%		
3	1-1-4		47	2.1%	2.1%	
4	1-1-5		47	4.3%	2.1%	
5	1-2-8		47	8.5%		
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	47			6.4%
7	2-1-2		47	10.6%	2.1%	44.7%
8	2-1-4		47			
9	2-2-2		47	6.4%	42.6%	19.1%
10	2-2-4		47	2.1%	2.1%	2.1%
11	2-2-8		47	10.6%	6.4%	
12	4-2-2	Group 3: Other	47		2.1%	6.4%
13	5-2-2		47		8.5%	
14	8-2-2		47		14.9%	4.3%
15	10-2-2		47			
Subtotal of the Group 1				55.3%	4.3%	0.0%
Subtotal of the Group 2				29.8%	53.2%	72.3%
Subtotal of the Group 3				0.0%	25.5%	10.6%
Total				**85.1%**	**83.0%**	**83.0%**

Table 5.38 Frequency of Triple-wise Phase Arrangement for Addition Projects

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	48	6.3%	4.2%	
2	1-1-2		48	29.2%		2.1%
3	1-1-4		48			
4	1-1-5		48	8.3%	2.1%	
5	1-2-8		48	8.3%	2.1%	
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	48	2.1%		10.4%
7	2-1-2		48	10.4%	4.2%	22.9%
8	2-1-4		48			4.2%
9	2-2-2		48	6.3%	27.1%	18.8%
10	2-2-4		48	4.2%		
11	2-2-8		48	4.2%	6.3%	
12	4-2-2	Group 3: Other	48		4.2%	2.1%
13	5-2-2		48		10.4%	
14	8-2-2		48		10.4%	
15	10-2-2		48			
Subtotal of the Group 1				52.1%	8.3%	2.1%
Subtotal of the Group 2				27.1%	37.5%	56.3%
Subtotal of the Group 3				0.0%	25.0%	2.1%
Total				**79.2%**	**70.8%**	**60.4%**

Table 5.39 Frequency of Triple-wise Phase Arrangement for Modernization Projects

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	53	5.7%		
2	1-1-2		53	22.6%	1.9%	5.7%
3	1-1-4		53	1.9%		
4	1-1-5		53	7.5%		
5	1-2-8		53	9.4%	1.9%	
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	53		1.9%	9.4%
7	2-1-2		53	7.5%	9.4%	24.5%
8	2-1-4		53	1.9%		5.7%
9	2-2-2		53	7.5%	20.8%	20.8%
10	2-2-4		53		1.9%	7.5%
11	2-2-8		53	3.8%		

Table 5.39 Frequency of Triple-wise Phase Arrangement for Modernization Projects (Continued)

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
12	4-2-2	Group 3: Other	53	1.9%	5.7%	5.7%
13	5-2-2		53		7.5%	1.9%
14	8-2-2		53		13.2%	1.9%
15	10-2-2		53		5.7%	
Subtotal of the Group 1				47.2%	3.8%	5.7%
Subtotal of the Group 2				20.8%	34.0%	67.9%
Subtotal of the Group 3				1.9%	32.1%	9.4%
Total				**69.8%**	**69.8%**	**83.0%**

5.5.3.3 Project Size

Tables 5.40 through 5.42 show the frequencies of triple-wise phase arrangements for light industrial projects categorized by project size. A similar trend of distribution and frequencies of patterns were noticed as in the analysis results by project natures. That is, the overall distribution does not show significant differences amongst the projects with different costs. Each pattern's frequency was also observed as similar across project sizes. Group 1, combined with patterns employing the sequential arrangement without concurrency between the front-end planning and engineering phases shows the highest use for all project sizes. Patterns in group 2 showed the highest use in the PCS combination. However, the smallest projects used the EPC combination with patterns in group 3 most frequently, which is different from bigger projects. A smaller portion of projects (13%) used pattern 9, compared to 36.2% of projects costing \$50MM-\$100MM and 42.6% of projects costing \$100MM-\$500MM.

Table 5.40 Frequency of Triple-wise Phase Arrangement for Project's Cost in $10MM-$50MM

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	54	5.6%	1.9%	
2	1-1-2		54	22.2%		5.6%
3	1-1-4		54	1.9%	1.9%	
4	1-1-5		54	7.4%	1.9%	
5	1-2-8		54	13.0%	1.9%	
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	54	1.9%	1.9%	13.0%
7	2-1-2		54	9.3%	7.4%	24.1%
8	2-1-4		54			3.7%
9	2-2-2		54	5.6%	13.0%	16.7%
10	2-2-4		54	1.9%	1.9%	
11	2-2-8		54	1.9%	7.4%	
12	4-2-2	Group 3: Other	54	1.9%	5.6%	5.6%
13	5-2-2		54		9.3%	
14	8-2-2		54		16.7%	1.9%
15	10-2-2		54		1.9%	
Subtotal of the Group 1				50.0%	7.4%	5.6%
Subtotal of the Group 2				20.4%	31.5%	57.4%
Subtotal of the Group 3				1.9%	33.3%	7.4%
Total				**72.2%**	**72.2%**	**70.4%**

Table 5.41 Frequency of Triple-wise Phase Arrangement for Project's Cost in $50MM-$100MM

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	47	8.5%	2.1%	
2	1-1-2		47	31.9%	2.1%	
3	1-1-4		47			
4	1-1-5		47	6.4%		
5	1-2-8		47	4.3%	2.1%	
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	47			8.5%
7	2-1-2		47	8.5%	8.5%	31.9%
8	2-1-4		47			4.3%
9	2-2-2		47	10.6%	36.2%	23.4%
10	2-2-4		47			6.4%
11	2-2-8		47	10.6%	4.3%	
12	4-2-2	Group 3: Other	47			2.1%
13	5-2-2		47		6.4%	
14	8-2-2		47		14.9%	2.1%
15	10-2-2		47		4.3%	
Subtotal of the Group 1				51.1%	6.4%	0.0%
Subtotal of the Group 2				29.8%	48.9%	74.5%
Subtotal of the Group 3				0.0%	25.5%	4.3%
Total				**80.9%**	**80.9%**	**78.7%**

Table 5.42 Frequency of Triple-wise Phase Arrangement for Project's Cost in $100MM-$500MM

Pattern	Combination of Patterns	Group of Patterns	Sample Size	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	47	2.1%		
2	1-1-2		47	34.0%		2.1%
3	1-1-4		47	2.1%		
4	1-1-5		47	6.4%	2.1%	
5	1-2-8		47	8.5%		
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases	47			4.3%
7	2-1-2		47	10.6%		36.2%
8	2-1-4		47	2.1%		2.1%
9	2-2-2		47	4.3%	42.6%	19.1%
10	2-2-4		47	4.3%	2.1%	4.3%
11	2-2-8		47	6.4%		
12	4-2-2	Group 3: Other	47		6.4%	6.4%
13	5-2-2		47		10.6%	2.1%
14	8-2-2		47		6.4%	2.1%
15	10-2-2		47			
Subtotal of the Group 1				53.2%	2.1%	2.1%
Subtotal of the Group 2				27.7%	44.7%	66.0%
Subtotal of the Group 3				0.0%	23.4%	10.6%

5.6 Summary and Conclusion

This chapter was designed to answer the second research question: "How can patterns of pairwise/triple-wise phase arrangements be quantified and what are the most common patterns of phase arrangements employed in the project development life cycle?" The research question was conducted following the process discussed in Chapter 3 and the research results were presented in Chapter 5. The below describes how it achieved and what was achieved.

The second research question was intended to focus on phase arrangements of capital projects. In Chapter 4, the relative position and sequence of phases in the project development life cycle was illustrated for the overall duration, with a focused on individual phase start and end times to represent their relative positions. The phase arrangements combinations were not taken into consideration. To identify various phase arrangements hidden in the overall schedule, the five phases in the development process were split into two phases combinations, such as the front-end planning and engineering phases, or the front-end planning and procurement phases. Amongst 10 combinations of pairwise phase arrangements, this research identified 11 unique patterns. Those patterns were grouped into three major categories including sequential phase arrangement, parallel phase arrangement, and reversed sequential phase arrangement. Below are the summary of the findings from the analysis of frequency of pairwise phase arrangements, where only 6 highly relevant phase combinations were selected and presented.

- In industrial projects, the most common pattern in front-end planning and engineering (FEP-ENG) and in front-end planning and procurement (FEP-PRO) were found to be pattern 1, at 64.8% and 79.4% respectively in which the phases were arranged in sequence without concurrency between two phases
- Pattern 2, which allows concurrency between two phases, was shown as the highest used in engineering and procurement (ENG-PRO) and in procurement and construction (PRO-CON) , 79.4% and 77.2% respectively
- Patterns 1 and 2 were equally used in the construction and startup phases
- Heavy industrial projects showed similar trends in industrial projects overall, but the sequential phase arrangement without concurrency had the highest use in the construction and startup phase
- Project types, natures, and different sizes did not make pattern frequencies differ from those in heavy industrial projects

- Light industrial projects showed similar trends as industrial projects and heavy industrial projects, but the sequential phase arrangement with concurrency had the highest use in the construction and startup phase
- Project types, natures, and different sizes did not differentiate the patterns' frequency from those in light industrial projects

The patterns of triple-wise phase arrangements were identified by combining existing pairwise phase arrangements. A total of 87 unique patterns were identified initially, but the 72 patterns (83%) had fewer than 15 cases, therefore only 15 patterns were prioritized and examined in this research. The summary below shows the pattern frequencies in the group level used in previous sections.

- In overall industrial projects, 46.8% of the projects employed sequential phase arrangement without concurrency between the front-end planning and engineering phases in the FEP combination
- 36.1% of the projects used the patterns categorized as other in the EPC combination: out of those projects, 27.3% of industrial projects had the procurement phase starting at the same time as the engineering phase started or procurement phase started even earlier than engineering phase did
- In the PCS combination, patterns in the sequential arrangement with concurrency between the procurement and construction phases showed the highest proportion of use at 71%
- In comparison between heavy and light industrial projects, a remarkable difference was noticed in the EPC combination: the highest frequency was found in patterns categorized as other in heavy industrial projects, whereas

patterns in which sequential arrangement with concurrency between engineering and procurement were found to be the most frequent in light industrial projects.

- Analyses at detailed levels such as projects categorized by project type, nature, or size did not show significant differences from results shown in industrial projects or heavy and light industrial projects.

In Chapter 5, various but unique patterns of pairwise and triple-wise phase arrangements were identified, along with their utilization level in capital projects. The utilization level was tested by various project characteristics to determine which project characteristics influenced it most. Chapter 6 describes how those identified patterns influence duration of the phases and project performance outcomes.

CHAPTER 6: ANALYSIS OF PHASE ARRANGEMENT IMPACT ON DURATION AND PERFORMANCE

6.1 INTRODUCTION

This chapter describes how various phase arrangement patterns influence duration of phases and project performance outcomes. Two types of durations in weeks were tested: combined and overall. The combined duration indicates the sum of the durations of each phase used in a phase arrangement. The overall duration is the duration of the phase arrangement and is calculated from the latest phase's end time minus the earliest phase's start time. The duration factor represents the percent duration. The combined duration factor measures the proportion of the combined duration of the phase arrangements over the sum of the durations of all phases. In contrast, the overall duration factor is a proportion of the overall duration of the phase arrangements over the overall duration of all phases, which subtracts the earliest phase's start time from the latest phase's end time. The purpose of comparison of the combined duration is to measure whether difference in duration exists regardless of the effect of various phase arrangements on duration. On the other hand, the comparison of the overall duration is to measure whether difference in duration exists with respect to the effect of various phase arrangements on duration. Five performance outcomes were examined to measure various impacts: schedule growth of a phase arrangement, cost growth of a phase arrangement, project schedule growth, project cost growth, and project change cost factor.

In order to conduct statistical analyses and to provide reliable results, this research needed to set a minimum sample size. Since several project characteristics were utilized as external factors, the most detailed-level categorization, i.e., heavy industrial - process - grass root projects costing $10MM-$50MM does not have a sufficient sample size. With respect to sample size per each triple-wise phase arrangement, this research set the minimum sample size as twenty. Any group having a sample size fewer than twenty was not presented. This applied to patterns or categories of project characteristics. As a result, only two project types were presented: process projects and pharmaceutical manufacturing projects. Project nature and project size were examined regardless of industry group and project type. Depending on the data set's normality and the number of dependent variables, independent sample t-test (MWU) or ANOVA (Kruskal-Wallis H test), was selected as a statistical method to measure the impact of phase arrangement on duration and performance outcomes. Mean and standard deviation (S.D) values in the result table in the following sections are bold and underlined when the group's data fits for normality and the test results are statistically significant by the t-test (ANOVA). If the median is bold and underlined, then the groups' data did not fit for normality, but the test result is statistically significant by the MWU (Krukal-Wallis H) test. In addition, a two-tailed test was selected at $p < 0.1$ since the underlying hypothesis was that the variables were not equal amongst given conditions. However, if the homogeneity of variance assumption among others is violated for ANOVA, the Welch's t-test was used instead. Compared to other chapters, this chapter is organized by phase combinations used for identifying patterns of phase arrangement in each section. In addition, normality test results are attached in the appendix.

6.2 Pairwise Phase Arrangement

As stated in Chapter 5, 11 unique patterns across all phase combinations were identified. Of 10 phase combinations, 6 phase combinations were selected to consider their relevance between two or three phases. This section is organized by those pair wise phase combinations, along with metric scores reflecting the impact of the phase arrangement on duration and performance outcomes.

6.2.1 Front-End Planning and Detailed Engineering

After removing patterns that had fewer than the designated sample size, only two remained for the combination of front-end planning and detailed engineering. The two remaining phase arrangements were pattern 1 and pattern 2. Pattern 1 illustrates two phases without concurrency, whereas pattern 2 represents two phases with some extent of concurrency, as shown in Table 6.1. The focus was to measure whether an early start of engineering prior to completion of front-end planning produced advantages in duration or performance outcomes.

Table 6.1 Description of Phase Arrangement

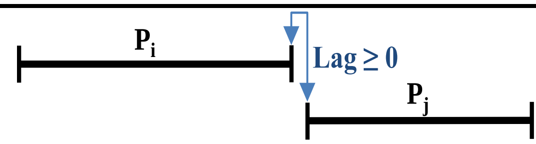
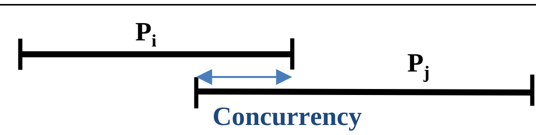
Description of pattern	Phase Arrangement Patterns includes: (P_i : the preceding phase and P_j: the succeeding phase)
Pattern 1: Sequential arrangement of two phases without concurrency: conventional phase arrangement	
Pattern 2: Sequential arrangement of two phases with concurrency	

Table 6.2 demonstrates the analysis results of duration in terms of combined and overall durations. The table provides corresponding sample size in given conditions. A green-shaded cell indicates shorter duration, or lower duration factor. Bold indicates the pattern’s mean (or median) is significantly different from the counterpart at the level of p<0.1, depending on the data’s normality. This means that the pattern had a statistically significant shorter duration, or lower duration factor.

The table illustrates that the group of projects having sequential arrangement without concurrency had a shorter combined duration and lower combined duration factor in most categories.

Statistically significant differences of combined duration was found in all industrial projects, heavy industrial projects, light industrial projects, grass roots projects, and projects costing \$100MM-\$500MM. All industrial projects with pattern 1 on front-end planning and detailed engineering had shorter combined duration in median at 77.9 weeks, compared to projects with pattern 2 at 91.6 weeks, and the difference in median was statistically significant by the MWU test (U = 10734.5, z = -2.619, p = 0.009<0.01). Amongst categories of project characteristics that presented a significant difference, grass roots projects showed a wide difference in median values of combined duration between project with pattern 1 and projects with pattern 2. Grass roots projects with pattern 1 had a median shorter combined duration at 83.9 weeks, compared to projects with pattern 2 at 116.5 weeks, and the difference in median was statistically significant by the MWU test (U = 681, z = -3.209, p = 0.001<0.01).

A statistically significant difference was noticed for all industrial projects, heavy and light industrial projects, process projects, addition projects, and projects costing \$10MM-\$50MM in the combined duration factors. According to the MWU test results, all industrial projects with pattern 1 on front-end planning and detailed engineering had a shorter combined duration factor at 37.8%, compared to projects with pattern 2 at 42.1%, and the difference was statistically significant (U = 10667, z = -2.929, p = 0.003<0.01). Compared to others that showed a significance difference in median value of combined duration factor, light industrial projects fit data normality. Statistically, projects with pattern 1 had shorter duration factor, at 30.5%, than projects with pattern 2 at 34.5% in mean, and the difference was statistically significant by the independent sample T test (t (141) = -1.991, p = 0.048 < 0.1).

In overall duration, projects employing pattern 2 had shorter mean durations in all categories except heavy industrial, grass roots projects, and projects costing $50MM-$100MM, but those projects did not have statistically significant difference. Moreover, no statistically significant difference in overall duration factor was not found in any category.

Table 6.3 shows the comparative results of the performance outcomes according to patterns. Statistical significance in median values was found only for project cost growth of projects costing $50MM-$100MM (U = 536, z = -2.396, p = 0.017 <0.01). Projects utilizing pattern 2 had significantly better median value of project cost growth (-2.8%) than projects employing pattern 1 (0.0%).

Table 6.2 Comparison of Duration for Front-End Planning and Detailed Engineering

Category (Standard Deviation)		Sequential arrangement of two phases w/o concurrency (Pattern 1)				Sequential arrangement of two phases w concurrency (Pattern 2)			
		Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor	Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor
All Industrial Projects	Mean	87.3 (46.8)	**37.8% (11.5%)**	94.1 (50.9)	65.1% (17.1%)	101.6 (52.3)	42.1% (11.6%)	89.1 (47.9)	68% (16.5%)
	Median	**77.9**	38.4%	82.1	67.9%	91.6	41.8%	81.2	71.1%
	N	230	230	230	230	113	115	114	115
Heavy Industrial Projects	Mean	97.9 (48.8)	**42.8% (9.4%)**	105.6 (53.6)	72.5% (13.9%)	115.4 (56)	47.4% (10.6%)	103 (51.6)	74.9% (13.7%)
	Median	**88.6**	42.0%	95.6	74.1%	105.5	45.1%	95.7	76.7%
	N	134	134	134	134	66	68	67	68
Light Industrial Projects	Mean	72.4 (39.5)	31% (10.5%)	78 (42.2)	54.8% (15.8%)	82.2 (39.5)	34.4% (8.1%)	69.3 (33.7)	58% (15.1%)
	Median	**66.4**	**30.5%**	70.9	52.1%	72.1	34.5%	56.6	56.8%
	N	96	96	96	96	47	47	47	47
Process Projects	Mean	94.3 (48.4)	**43.1% (9.4%)**	101.1 (52.5)	73.4% (14.4%)	102.8 (39.2)	47.3% (10.6%)	90.9 (35.2)	74.1% (13.3%)
	Median	**82.9**	42.5%	91.4	75.9%	104.1	45.7%	91.5	76.0%
	N	104	104	104	104	52	52	52	52
Pharmaceutical Manufacturing Projects	Mean	75.3 (41.9)	29.9% (9.6%)	80.7 (42.3)	55.8% (15.5%)	84.8 (39.4)	32.8% (6.7%)	73.5 (35.5)	54.7% (12.4%)
	Median	70.6	29.9%	78.4	53.9%	76.6	32.7%	65.2	53.7%
	N	62	62	62	62	30	30	30	30
Grass Roots	Mean	91.2 (43)	35.5% (11.1%)	97.8 (46.3)	61.2% (16.8%)	129.4 (64.8)	38.3% (9.4%)	111.7 (53.2)	65.6% (16.3%)
	Median	**83.9**	36.2%	89.4	62.2%	116.5	38.6%	100.9	65.9%
	N	66	66	66	66	34	34	34	34
Addition	Mean	83.8 (49.9)	**37.7% (10.8%)**	90.5 (55.5)	65.1% (17.6%)	84.5 (40.4)	43.1% (11%)	70.7 (32.2)	67.5% (16.4%)
	Median	73.6	36.7%	75.6	67.0%	72.4	43.1%	59.6	71.4%
	N	80	80	80	80	37	38	37	38
Modernization	Mean	87.5 (46.8)	**39.8% (12.2%)**	94.6 (50.3)	68.2% (16.5%)	94.1 (41.1)	44.2% (13%)	87.2 (48.4)	70.3% (16.8%)
	Median	79.8	39.6%	86.9	72.4%	84.3	43.8%	76.6	75.1%
	N	84	84	84	84	42	43	43	43
$10MM-$50MM	Mean	72.5 (42)	**39.4% (12.5%)**	79.3 (44.8)	65.1% (17.5%)	77.8 (30.6)	45.8% (11.3%)	70 (41.4)	68.6% (18.1%)
	Median	65.1	39.7%	73.6	67.3%	74.1	45.0%	59.6	71.7%
	N	107	107	107	107	42	43	43	43
$50MM-$100MM	Mean	86.9 (39.8)	37.6% (11.4%)	90.6 (41.9)	65.8% (17.7%)	99.7 (59.4)	39.9% (13.1%)	90.7 (56.5)	66.4% (15.8%)
	Median	77.1	37.6%	77.7	69.0%	80.4	36.9%	74.1	67.5%
	N	49	49	49	49	32	32	32	32
$100MM-$500MM	Mean	108.8 (49.7)	**35.8% (9.7%)**	117.9 (56.3)	64.6% (16.3%)	128.7 (52.8)	40% (9.6%)	108.9 (38.8)	68.7% (15.6%)
	Median	**100.7**	36.1%	107.7	68.2%	125.9	40.0%	108.6	72.6%
	N	74	74	74	74	39	40	39	40

Green shading indicates shorter duration or lower duration factor. Bold indicates a $p<0.1$.

Table 6.3 Comparison of Performance Outcomes for Front-End Planning and Detailed Engineering

Category (Standard Deviation)		Sequential arrangement of two phases w/o concurrency (Pattern 1)					Sequential arrangement of two phases w concurrency (Pattern 2)				
		SGPA	CGPA	PSG	PCG	PCCF	SGPA	CGPA	PSG	PCG	PCCF
All Industrial Projects	Mean	10.6% (17.7%)	4.6% (21.1%)	5.3% (12%)	-0.6% (13%)	5.1% (6%)	11.8% (17.3%)	0.9% (20.7%)	4.2% (11.5%)	-2.5% (14.4%)	5.6% (5.8%)
	Median	6.8%	0.6%	2.0%	-0.3%	3.8%	6.9%	-0.5%	2.1%	-2.0%	4.8%
	N	211	182	207	222	184	106	86	107	113	94
Heavy Industrial Projects	Mean	9.5% (16.1%)	4.4% (23%)	5% (12.6%)	-1.5% (13.6%)	4% (5.2%)	9.6% (15.6%)	-1.5% (20.1%)	5.1% (12%)	-3.2% (16.6%)	4.6% (5.2%)
	Median	4.9%	0.0%	0.4%	-1.6%	3.5%	6.0%	-1.1%	2.4%	-3.3%	4.0%
	N	120	111	120	130	105	65	56	65	68	54
Light Industrial Projects	Mean	12% (19.6%)	4.8% (17.9%)	5.8% (11.2%)	0.8% (12.1%)	6.7% (6.7%)	15.2% (19.4%)	5.4% (21.4%)	2.7% (10.7%)	-1.5% (10.4%)	7% (6.2%)
	Median	7.5%	1.7%	3.8%	0.0%	4.3%	10.3%	0.3%	1.9%	-1.3%	6.3%
	N	91	71	87	92	79	41	30	42	45	40
Process Projects	Mean	8.4% (15.2%)	2.2% (20.5%)	4.2% (12%)	-1.6% (13.7%)	3.7% (5.4%)	6.9% (13.1%)	-3.2% (17.6%)	4.3% (11.6%)	-3.8% (14.4%)	5.1% (5.2%)
	Median	4.9%	-0.3%	0.5%	-1.5%	3.4%	4.3%	-2.0%	0.0%	-3.3%	4.0%
	N	90	85	91	102	82	49	44	49	52	42
Pharmaceutical Manufacturing Projects	Mean	12.9% (19.9%)	5.2% (20.7%)	6.7% (11.5%)	2.2% (13.3%)	6.7% (6.7%)	17.4% (18%)	3.9% (17.3%)	4.2% (9.9%)	-2.1% (11.3%)	6.3% (5.1%)
	Median	9.1%	1.3%	4.6%	0.7%	4.1%	13.4%	-2.2%	3.1%	-3.4%	6.0%
	N	58	44	55	58	48	26	20	26	28	24
Grass Roots	Mean	9.3% (15.4%)	7.7% (20.4%)	5.5% (11.1%)	0.8% (13.7%)	4.7% (7%)	16.1% (16.7%)	-0.7% (25.2%)	6% (11.2%)	-2.1% (17.3%)	6.1% (6.1%)
	Median	7.9%	4.1%	4.3%	0.0%	3.3%	10.1%	-1.0%	1.9%	-3.3%	5.2%
	N	60	50	59	64	48	34	21	34	33	25
Addition	Mean	13.4% (21%)	4.8% (20.6%)	4% (12.6%)	-1.9% (14.2%)	4.9% (5.6%)	7.9% (12.2%)	-0.4% (19.6%)	2% (11.4%)	-4.1% (13.2%)	5.2% (6.6%)
	Median	8.7%	0.1%	0.1%	-1.6%	3.6%	4.1%	-4.2%	0.7%	-4.0%	3.9%
	N	73	62	72	77	64	33	29	36	38	32

Green shading indicates better performance (the lower is the better). Bold indicates a $p<0.1$. SGPA, CGPA, PSG, PCG, and PCCF stand for schedule growth of phase arrangement, cost growth of phase arrangement, project schedule growth, project cost growth and project change cost factor respectively.

Table 6.3 Comparison of Performance Outcomes for Front-End Planning and Detailed Engineering (Continued)

Category (Standard Deviation)		Sequential arrangement of two phases w/o concurrency (Pattern 1)					Sequential arrangement of two phases w concurrency (Pattern 2)				
		SGPA	CGPA	PSG	PCG	PCCF	SGPA	CGPA	PSG	PCG	PCCF
Modernization	Mean	8.9% (15.8%)	2.1% (22.1%)	6.5% (12.2%)	-0.4% (11.2%)	5.6% (5.8%)	11.2% (20.6%)	2.9% (19.1%)	4.6% (11.9%)	-1.5% (13.1%)	5.6% (4.9%)
	Median	4.0%	0.2%	1.2%	0.0%	4.6%	6.0%	0.9%	3.7%	0.0%	5.2%
	N	78	70	76	81	72	39	36	37	42	37
$10MM-$50MM	Mean	8.4% (16.1%)	0.5% (20.5%)	4% (12.5%)	-3% (12.2%)	4.4% (5.7%)	10.8% (15.1%)	-1.1% (23.3%)	3.1% (12.4%)	-3.1% (13%)	6% (6.2%)
	Median	4.6%	-0.9%	0.4%	-3.3%	3.8%	6.5%	-2.6%	1.5%	-0.1%	5.5%
	N	96	85	93	104	84	39	37	41	43	41
$50MM-$100MM	Mean	15.2% (19.8%)	4.7% (18.1%)	5.6% (10.6%)	1.1% (11.6%)	5.8% (6.5%)	13.3% (19.8%)	1.8% (19.9%)	3.7% (11.3%)	-7% (13.2%)	5.3% (5.5%)
	Median	10.2%	1.2%	1.6%	0.0%	4.2%	6.1%	-1.1%	1.8%	**-2.8%**	3.8%
	N	46	41	48	49	43	30	23	29	32	26
$100MM-$500MM	Mean	10.7% (18%)	10.7% (23%)	7% (12.3%)	1.9% (14.5%)	5.8% (6.1%)	11.5% (17.6%)	3% (17.9%)	5.7% (10.8%)	1.8% (15.9%)	5.3% (5.5%)
	Median	7.4%	7.9%	4.8%	0.7%	3.5%	8.2%	0.5%	3.1%	-3.1%	5.1%
	N	69	56	66	69	57	37	26	37	38	27

Green shading indicates better performance (the lower is the better). Bold indicates a p<0.1. SGPA, CGPA, PSG, PCG, and PCCF stand for schedule growth of phase arrangement, cost growth of phase arrangement, project schedule growth, project cost growth and project change cost factor respectively.

6.2.2 Front-End Planning and Procurement

After removing patterns that had fewer than the designated sample size, only two patterns remained for the combination of front-end planning and procurement. The two remaining phase arrangements were pattern 1 and pattern 2. An illustration of the patterns is in Table 6.4. The focus of this analysis was to measure whether an early start of procurement prior to completion of front-end planning produced advantages in duration or performance outcomes.

Table 6.4 Description of Phase Arrangement

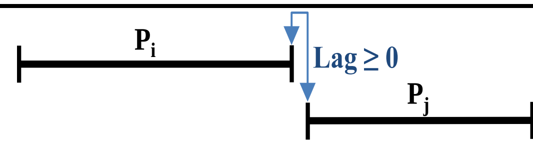
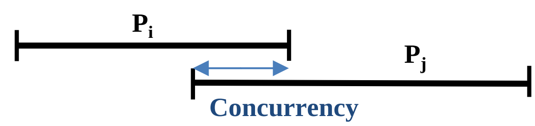
Description of pattern	Phase Arrangement Patterns includes: (P_i : the preceding phase and P_j: the succeeding phase)
Pattern 1: Sequential arrangement of two phases without concurrency: conventional phase arrangement	
Pattern 2: Sequential arrangement of two phases with concurrency	

Table 6.5 demonstrates the analysis results of duration in terms of combined and overall durations. As shown in the previous section, front-end planning and detailed engineering, the benefits of combined duration were found for projects that used pattern 1, whereas projects that utilized pattern 2 had an advantage in mean overall duration except for grass roots projects and projects costing \$50MM-\$100MM. No statistical significance in overall duration or overall duration factor was found in the categories, however.

A remarkable point is that projects with early procurement involvement had shorter overall duration with statistically significant outcomes in median values at $p<0.1$ for all industrial projects, heavy industrial projects, grass roots projects, addition projects, and projects costing \$100MM-\$500MM. In detail, for projects costing \$100MM-\$500MM, projects with pattern 2 in which procurement started earlier than front-end planning was complete had a radical difference of overall duration in median of 103.1 weeks, compared to projects with pattern 1 with a median of 134.7 weeks. According to the MWU test, the difference in median was statistically significant at $p<0.1$ (U = 982, z = -3.062, p = 0.002 < 0.01).

Table 6.6 summarizes performance outcomes by patterns in the given categories of project characteristics. Better performance outcomes were found for projects that employed pattern 2 in most categories and performance outcome metrics. According to the MWU test result, for modernization projects, project with pattern 2 had better cost growth of phase arrangement at -10%, compared to projects with pattern 1 at -3.2%, and the difference in median was statistically significant at $p<0.1$ (U = 893, z = -3.011, p = 0.003 < 0.1). By the independent sample T test, for projects costing \$50MM-\$100MM, projects with pattern 2 had an improved cost growth of phase arrangement at -9.8%, compared to projects with pattern 1 at -3.4%, and the difference in mean was statistically significant at $p<0.1$ (t (56) = 1.689, p = 0.097 < 0.1). It was observed that projects with pattern 2, for light industrial projects, had better project cost growth at -0.5%, compared to projects with pattern 1 at 0.5%, and the difference in mean was statistically significant at $p<0.1$ by the independent sample T test (t (134) = 0.492, p = 0.01 < 0.1). It shows that pattern 2 was associated with better project change cost factor for heavy industrial projects and process projects at $p<0.1$. According to MWU test results, projects with pattern 2, for process projects, had an improved change cost factor at 2.3%, compared to projects with pattern 1 at 4.4%, the difference in median was statistically significant (U = 1488, z = -1784, p = 0.074 < 0.1).

Table 6.5 Comparison of Duration for Front-End Planning and Procurement

Category (standard deviation)		Sequential arrangement of two phases w/o concurrency (Pattern 1)				Sequential arrangement of two phases w concurrency (Pattern 2)			
		Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor	Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor
All Industrial Projects	Mean	96.4 (52)	**40.1% (9.8%)**	113.2 (59.7)	75.4% (15.1%)	114.6 (55.3)	47.5% (9.9%)	95.6 (46.7)	75.7% (13.4%)
	Median	**91.3**	39.7%	100.9	78.7%	104.4	46.8%	**86**	76.9%
	Sample	219	219	219	219	124	125	124	125
Heavy Industrial Projects	Mean	104.8 (57.1)	**42.8% (9.6%)**	122.3 (64.2)	78.4% (13.4%)	120.3 (57.7)	50.5% (9.7%)	99.8 (48.4)	77.3% (12.4%)
	Median	**98.4**	43.5%	105.3	81.5%	105.7	50.3%	**88.2**	77.0%
	Sample	127	127	127	127	74	75	74	75
Light Industrial Projects	Mean	84.8 (41.5)	**36.4% (8.9%)**	100.6 (50.6)	71.3% (16.5%)	106.2 (50.8)	43.1% (8.6%)	89.4 (43.7)	73.1% (14.6%)
	Median	**83.5**	35.8%	91.3	75.2%	95	42.9%	78.8	76.6%
	Sample	92	92	92	92	50	50	50	50
Process Projects	Mean	97.6 (54.9)	**43% (10.2%)**	113.3 (61.8)	78.2% (14%)	110.2 (39.7)	51% (9.5%)	91.3 (33.8)	77.2% (12.6%)
	Median	**89.8**	44.4%	98.5	80.5%	105.6	51.9%	85.9	79.2%
	Sample	96	96	96	96	59	59	59	59
Pharmaceutical Manufacturing Projects	Mean	90.3 (41.9)	**36.6% (8.6%)**	103.4 (49.9)	71.5% (16.8%)	109.8 (51.1)	43.5% (9%)	94.2 (44.2)	72.9% (15.1%)
	Median	96.6	35.9%	102.6	75.7%	99.6	43.1%	87.9	76.6%
	Sample	55	55	55	55	36	36	36	36
Grass Roots	Mean	110.1 (49.5)	**38.7% (9.6%)**	130.3 (58.6)	73.7% (16.2%)	130.8 (66.5)	44% (8.3%)	105.6 (47.4)	72.6% (14.6%)
	Median	106.6	39.6%	117.3	76.0%	107	43.7%	**97.4**	76.0%
	Sample	57	57	57	57	41	41	40	41
Addition	Mean	91.1 (52)	**39.7% (10%)**	106.1 (58.3)	76.1% (14.6%)	102.3 (52.1)	47.7% (9.9%)	84.4 (43.1)	74.7% (13.2%)
	Median	86.9	40.1%	93.7	78.0%	91.6	49.8%	**75.1**	75.8%
	Sample	81	81	81	81	37	37	37	37
Modernization	Mean	91.9 (52.7)	**41.5% (9.8%)**	108.2 (60.3)	75.9% (15%)	110.1 (43.2)	50.4% (10.5%)	95.9 (47.7)	79.1% (12%)
	Median	**78.1**	39.7%	93.4	80.0%	105.7	50.3%	86.1	79.5%
	Sample	81	81	81	81	46	47	47	47
\$10MM-\$50MM	Mean	76.5 (44.6)	**41.4% (11%)**	91.9 (52.7)	74% (15.8%)	97.3 (44.3)	50.9% (9.9%)	84.2 (45.4)	77.2% (11.7%)
	Median	**63.9**	41.0%	79.5	78.1%	96.6	51.3%	79.3	79.2%
	Sample	102	102	102	102	52	53	53	53
\$50MM-\$100MM	Mean	95.6 (52.4)	**39% (9.1%)**	110.5 (54.6)	77.2% (13.9%)	108.1 (53.7)	44.4% (9.1%)	89.4 (37.9)	74.4% (14.3%)
	Median	89	39.4%	93.4	79.0%	95.9	43.5%	82.7	76.4%
	Sample	49	49	49	49	28	28	27	28
\$100MM-\$500MM	Mean	126.7 (47.9)	**39% (8.3%)**	147.1 (58.6)	76.1% (15%)	139.2 (60)	45.4% (9.4%)	113.1 (48.7)	74.5% (15%)
	Median	121.6	39.1%	134.7	78.2%	128.1	44.5%	**103.1**	76.1%
	Sample	68	68	68	68	44	44	44	44

Green shading indicates shorter duration or lower duration factor. Bold indicates a $p<0.1$.

Table 6.6 Comparison of Performance Outcomes for Front-End Planning and Procurement

Category (Standard Deviation)		Sequential arrangement of two phases w/o concurrency (Pattern 1)					Sequential arrangement of two phases w concurrency (Pattern 2)				
		SGPA	CGPA	PSG	PCG	PCCF	SGPA	CGPA	PSG	PCG	PCCF
All Industrial Projects	Mean	9.6% (17.3%)	-4.6% (16.7%)	5.4% (13.8%)	-1% (12%)	5.8% (6.3%)	8.2% (12.9%)	-8.2% (13.3%)	4.6% (10.3%)	-2% (14%)	4.8% (5.7%)
	Median	6.2%	-4.8%	1.8%	-0.4%	4.3%	6.2%	**-7.8%**	2.4%	-2.0%	4.3%
	N	200	162	198	210	180	116	86	115	121	100
Heavy Industrial Projects	Mean	8.2% (16.8%)	-5.9% (15.9%)	5.1% (14.4%)	-2% (12.2%)	4.9% (5.3%)	7.4% (10.1%)	-8.1% (12.1%)	4.6% (9.6%)	-3% (15.4%)	3% (4.6%)
	Median	4.8%	-5.4%	0.4%	-1.7%	4.4%	5.7%	-8.6%	2.4%	-4.5%	**2.5%**
	N	115	103	115	122	105	70	57	70	73	56
Light Industrial Projects	Mean	11.5% (17.7%)	-2.5% (17.9%)	5.7% (13%)	0.5% (11.6%)	7% (7.3%)	9.4% (16.4%)	-8.3% (15.7%)	4.6% (11.5%)	**-0.5% (11.5%)**	7.1% (6.2%)
	Median	7.7%	-3.2%	2.3%	0.0%	4.3%	7.2%	**-7.1%**	4.3%	-1.2%	6.1%
	N	85	59	83	88	75	46	29	45	48	44
Process Projects	Mean	7.1% (17.6%)	-5.8% (16.2%)	4.6% (14.6%)	-1.6% (12.3%)	4.9% (5.6%)	6.4% (10.2%)	-8.2% (10.2%)	2.9% (7.6%)	-3.9% (14.9%)	3% (4.6%)
	Median	3.4%	-5.2%	1.1%	-1.5%	4.4%	4.7%	-9.2%	0.5%	-5.6%	**2.3%**
	N	84	78	85	93	80	54	46	54	59	46
Pharmaceutical Manufacturing Projects	Mean	10.3% (17.7%)	-4.2% (17.9%)	6.6% (14.4%)	2% (12.9%)	7% (7.6%)	12.9% (14.7%)	-7.7% (18%)	7.2% (10.8%)	-0.9% (12.8%)	7% (5.4%)
	Median	7.9%	-5.0%	3.7%	1.5%	3.6%	9.4%	-6.9%	5.2%	-1.9%	6.1%
	N	49	37	48	51	42	34	21	33	34	30
Grass Roots	Mean	8.2% (13.7%)	-1.4% (15.9%)	5.4% (11.6%)	0.5% (11.6%)	7% (7.9%)	8.9% (11.9%)	-6.1% (16.2%)	5.7% (10.6%)	-0.9% (15.7%)	3.6% (5.9%)
	Median	7.9%	-0.7%	4.1%	0.0%	4.1%	6.8%	-5.5%	2.3%	-3.2%	4.0%
	N	51	40	51	54	42	41	23	40	39	31
Addition	Mean	8.2% (17.9%)	-10.2% (17.3%)	4.2% (13.7%)	-2.4% (13.2%)	5.1% (5.5%)	7.7% (13.7%)	-6.4% (12.4%)	1.8% (8.8%)	-4.3% (13.3%)	5% (6.5%)
	Median	2.5%	-12.2%	0.2%	-1.6%	3.8%	6.3%	-7.1%	1.5%	-3.3%	3.9%
	N	75	57	75	78	68	33	21	33	36	29

Green shading indicates better performance (the lower is the better). Bold indicates a p<0.1. SGPA, CGPA, PSG, PCG, and PCCF stand for schedule growth of phase arrangement, cost growth of phase arrangement, project schedule growth, project cost growth and project change cost factor respectively.

Table 6.6 Comparison of Performance Outcomes for Front-End Planning and Procurement (Continued)

Category (Standard Deviation)		Sequential arrangement of two phases w/o concurrency (Pattern 1)					Sequential arrangement of two phases w concurrency (Pattern 2)				
		SGPA	CGPA	PSG	PCG	PCCF	SGPA	CGPA	PSG	PCG	PCCF
Modernization	Mean	12% (18.7%)	-1.8% (15.5%)	6.6% (15.3%)	-0.6% (10.9%)	5.7% (5.8%)	8% (13.6%)	-10.2% (12.1%)	5.8% (11%)	-1.2% (13.1%)	5.6% (5%)
	Median	8.3%	-3.2%	1.2%	0.0%	4.8%	5.1%	**-10.0%**	4.0%	-0.3%	5.3%
	N	74	65	72	78	70	42	42	42	46	40
$10MM-$50MM	Mean	8.3% (16.9%)	-6.8% (15.8%)	4.8% (15.5%)	-2.9% (11.7%)	5.1% (5.6%)	4.7% (11.1%)	-9.2% (12.1%)	2.2% (8.3%)	-4.5% (11.8%)	4.4% (6.3%)
	Median	2.7%	-5.0%	0.4%	-2.9%	4.1%	4.9%	-9.1%	0.5%	-3.0%	4.8%
	N	91	75	89	99	86	49	37	49	52	43
$50MM-$100MM	Mean	13.3% (18.1%)	-3.4% (16%)	4.2% (11.6%)	0.2% (10.6%)	6.6% (6.5%)	10.7% (14.1%)	**-9.8% (9.3%)**	6.8% (9.9%)	-3.9% (13.6%)	4.6% (5%)
	Median	10.0%	-3.1%	1.8%	0.0%	4.5%	7.2%	-9.1%	2.9%	-1.7%	3.4%
	N	46	36	47	48	43	26	22	26	28	23
$100MM-$500MM	Mean	8.9% (17.1%)	-2.4% (18.3%)	7.1% (12.7%)	1.2% (13.2%)	6.3% (7%)	10.8% (13.5%)	-5.4% (17.3%)	6.1% (12.3%)	2.4% (15.9%)	5.4% (5.4%)
	Median	6.3%	-5.4%	4.2%	0.7%	3.3%	7.7%	-6.4%	3.8%	-1.1%	5.2%
	N	63	51	62	63	51	41	27	40	41	34

Green shading indicates better performance (the lower is the better). Bold indicates a p<0.1. SGPA, CGPA, PSG, PCG, and PCCF stand for schedule growth of phase arrangement, cost growth of phase arrangement, project schedule growth, project cost growth and project change cost factor respectively.

6.2.3 Detailed Engineering and Procurement

After removing patterns that had fewer than the designated sample size, three patterns remained for the combination of detailed engineering and procurement. The three remaining phase arrangements were patterns 2, 4, and 6. A description of the patterns can be found in Table 6.7. The analysis of this combination was performed to check whether there is a specific phase arrangement that leads to duration or other performance outcome advantages.

Table 6.7 Description of Phase Arrangement

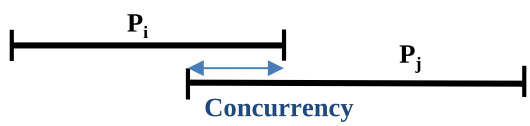
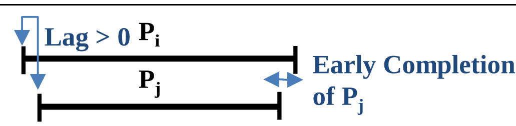
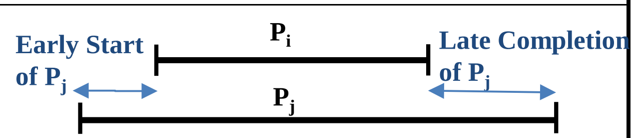
Description of pattern	Phase Arrangement Patterns includes: (P_i : the preceding phase and P_j: the succeeding phase)
Pattern 2: Sequential arrangement of two phases with concurrency	
Pattern 4: Parallel arrangement of two phases with longer predecessor	
Pattern 8: Reversed sequential arrangement of two phases with concurrency and longer successor	

Table 6.8 illustrates the results of duration analysis with respect to combined and overall durations. Projects that employed pattern 4 had the lowest but statistically significant overall duration factor in all industrial projects, heavy industrial projects, and process projects at p<0.1. For heavy industrial projects, projects with pattern 4 had the significantly shortest duration at 55 weeks, compared to projects with pattern 2 at 74.4 weeks and pattern 8 at 69.6 weeks by Kruskal-Wallis H Test at p<0.1 (X^2 = 5.114, p = 0.078 < 0.1). In addition, those projects showed the lowest combined duration factor in process

projects at $p<0.05$. When comparison was only available for projects having pattern 2 against projects having pattern 8, the former projects demonstrated lower mean overall duration factor in light industrial projects, pharmaceutical manufacturing projects, grass roots projects, modernization projects.

Table 6.9 presents performance outcomes by patterns for the various project characteristic categories. No statistically significant patterns were found in these breakout categories, however.

Table 6.8 Comparison of Duration for Detailed Engineering and Procurement

Category (Standard Deviation)		Sequential arrangement of two phases w/ concurrency (Pattern 2)				Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor (Pattern 4)				Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor (Pattern 8)			
		Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor	Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor	Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor
All Industrial Projects	Mean	115.1 (60.2)	47.7% (12%)	78.7 (41.9)	**54.6% (14.3%)**	110.5 (59.1)	47% (10%)	65.5 (33.8)	**46.5% (14.3%)**	125.7 (64.3)	51.4% (7.1%)	81.8 (40.9)	**63.3% (13.8%)**
	Median	104.3	**46.9%**	70.8	55.5%	89.9	47.6%	**55.4**	46.2%	114	**52.1%**	**74.4**	65.2%
	N	125	126	126	126	38	40	38	40	62	62	63	63
Heavy Industrial Projects	Mean	128.2 (66.7)	52.5% (12.8%)	87.2 (48)	55.8% (14.6%)	113.9 (62.4)	49.1% (8.8%)	67.4 (36)	**47.9% (13.7%)**	131.5 (71.5)	53.8% (5.7%)	82.9 (44.3)	60.9% (12.4%)
	Median	113	51.4%	**74.4**	55.8%	87.3	48.3%	**55**	46.2%	114.3	53.1%	69.6	62.3%
	N	57	58	58	58	31	33	31	33	32	32	33	33
Light Industrial Projects	Mean	104.2 (52.2)	43.6% (9.5%)	71.4 (34.6)	**53.5% (14.2%)**					119.5 (56.1)	48.8% (7.6%)	80.6 (37.4)	66% (14.9%)
	Median	99.1	**44.7%**	69.4	55.5%					113.6	46.7%	75.6	66.6%
	N	68	68	68	68					30	30	30	30
Process Projects	Mean	105.3 (43.2)	49.5% (9.9%)	75.3 (41.6)	55% (15%)	**97.2 (50.3)**	46.4% (7%)	**57.5 (27.3)**	**44.3% (11.5%)**	**122.2 (46.4)**	53.9% (5.8%)	**80.2 (38.2)**	**61.2% (12.4%)**
	Median	104.1	49.3%	63.3	57.7%	85.6	47.4%	49.9	45.4%	114.3	53.4%	71.9	62.3%
	N	36	37	37	37	26	26	26	26	25	25	26	26
Pharmaceutical Manufacturing Projects	Mean	110.8 (56.8)	44.9% (9%)	74.2 (36.1)	**53.6% (12.9%)**					124.8 (57.5)	48.5% (7.4%)	84.3 (37.9)	67.4% (13.8%)
	Median	102.1	45.7%	70.9	56.6%					116.9	46.7%	79.3	69.1%
	N	40	40	40	40					26	26	26	26
Grass Roots	Mean	128.6 (61.7)	**43.7% (9.9%)**	89 (43.4)	**52.7% (14.4%)**					150.4 (76.3)	51% (6.7%)	92.9 (43.2)	62.2% (10.1%)
	Median	118	45.9%	81.4	57.0%					127.8	52.3%	79	65.0%
	N	41	41	41	41					22	22	22	22
Addition	Mean	96 (42.4)	47.9% (10%)	64.9 (30.4)	54.6% (15.4%)								
	Median	92.1	47.6%	58	54.2%								
	N	43	43	43	43								

Green-shading indicates the shortest (shorter if only two groups exist) duration or the lowest duration factor. Bold indicates a $p<0.1$: note that two, or more than 2 bolds in the same metric and category indicate duration, or duration factor, of a group is significantly different from each other, or among others in post-hoc test.

Table 6.8 Comparison of Duration for Detailed Engineering and Procurement (Continued)

Category (Standard Deviation)		Sequential arrangement of two phases w/ concurrency (Pattern 2)				Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor (Pattern 4)				Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor (Pattern 8)			
		Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor	Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor	Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor
Modernization	Mean	121.7 (70.2)	51.5% (14.4%)	82.7 (47.3)	**56.3% (13.2%)**					114.3 (60.4)	52.5% (6.7%)	78.4 (46.2)	67% (15.2%)
	Median	106.3	48.8%	73.8	56.3%					107.4	52.3%	68.1	71.5%
	N	41	42	42	42					22	22	23	23
$10MM-$50MM	Mean	90 (46.2)	49.6% (14%)	61.6 (32.2)	52% (14%)	78.5 (37.3)	45.9% (11.3%)	47.9 (20.1)	44.2% (15.3%)	83.8 (35.6)	50.7% (7.2%)	57.3 (24.7)	**60.5% (15.2%)**
	Median	81.9	47.2%	52.1	52.7%	74.9	44.7%	46.2	40.7%	90.4	48.6%	56.4	62.4%
	N	55	55	55	55	20	21	20	21	23	23	23	23
$50MM-$100MM	Mean	117.9 (64.7)	45.3% (9.5%)	78.4 (40.3)	56.1% (13.3%)								
	Median	106.3	44.2%	73.6	56.3%								
	N	31	31	31	31								
$100MM-$500MM	Mean	148.4 (58.7)	47% (10.4%)	102.4 (44)	56.9% (15.3%)					153.7 (55.8)	50.4% (6%)	100.6 (40.3)	63.6% (12.4%)
	Median	155.6	46.8%	99.9	60.0%					134.2	51.3%	79.9	63.9%
	N	39	40	40	40					24	24	25	25

Green-shading indicates the shortest (shorter if only two groups exist) duration or the lowest duration factor. Bold indicates a p<0.1: note that two, or more than 2 bolds in the same metric and category indicate duration, or duration factor, of a group is significantly different from each other, or among others in post-hoc test.

Table 6.9 Comparison of Performance Outcomes for Detailed Engineering and Procurement

Category (Standard Deviation)		Sequential arrangement of two phases w/ concurrency (Pattern 2)					Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor (Pattern 4)					Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor (Pattern 8)				
		SGPA	CGPA	PSG	PCG	PCCF	SGPA	CGPA	PSG	PCG	PCCF	SGPA	CGPA	PSG	PCG	PCCF
All Industrial Projects	Mean	15.3% (23%)	-3.7% (12.3%)	5.7% (13%)	-1.4% (11.7%)	6.2% (6%)	14.7% (22%)	-3.5% (11.9%)	4.5% (13.9%)	-1.2% (10.2%)	4.9% (6.5%)	14% (22.1%)	-5.8% (13.6%)	3.9% (11%)	-3.1% (15%)	5.3% (4.8%)
	Median	12.2%	-3.0%	2.3%	-1.1%	4.4%	11.9%	-6.8%	1.8%	-0.4%	4.7%	7.2%	-5.4%	2.1%	-3.1%	4.1%
	N	119	97	113	118	103	39	39	39	40	37	61	49	59	61	52
Heavy Industrial Projects	Mean	13.1% (23.9%)	-5.9% (11.8%)	4.3% (12.5%)	-4.2% (12.4%)	5.1% (4.8%)	12.9% (21.6%)	-3.5% (11.5%)	5.4% (14.7%)	-0.9% (10.7%)	5.4% (6.2%)	10.7% (19.6%)	-7.4% (14.9%)	5.9% (11%)	-3.8% (18.6%)	3.8% (3.1%)
	Median	10.3%	-5.0%	0.0%	-4.4%	4.2%	12.4%	-4.7%	3.1%	0.4%	4.9%	6.1%	-6.0%	2.4%	-5.0%	2.8%
	Sample	56	50	53	54	46	32	32	33	33	32	31	28	31	31	24
Light Industrial Projects	Mean	17.3% (22.2%)	-1.4% (12.5%)	7.1% (13.4%)	0.9% (10.6%)	7.1% (6.8%)						17.3% (24.3%)	-3.5% (11.7%)	1.8% (10.8%)	-2.4% (10.3%)	6.5% (5.6%)
	Median	14.7%	-2.0%	4.0%	0.3%	4.7%						9.7%	-4.8%	1.1%	-2.0%	5.0%
	Sample	63	47	60	64	57						30	21	28	30	28
Process Projects	Mean	13.2% (27.3%)	-5.8% (11.2%)	4.7% (14%)	-3.2% (12.5%)	5.6% (5.4%)	13% (23.3%)	-5.1% (11.4%)	5.1% (15%)	-1.2% (11.6%)	5.2% (6.5%)	10.7% (21.5%)	-9.7% (11.9%)	4% (8.7%)	-5.3% (16.5%)	4.1% (3.3%)
	Median	11.4%	-5.7%	0.0%	-4.9%	4.0%	12.2%	-8.6%	3.6%	2.0%	4.7%	5.1%	-7.2%	1.9%	-5.3%	3.5%
	Sample	35	33	32	34	29	26	25	26	26	25	24	24	24	26	21
Pharmaceutical Manufacturing Projects	Mean	17.1% (22.5%)	-0.3% (15.2%)	8.5% (14.4%)	2.1% (12.6%)	7.2% (6.6%)						14.3% (20.5%)		2.4% (11.5%)	-2.5% (10.9%)	6.9% (6%)
	Median	14.8%	-1.7%	6.5%	2.7%	5.7%						9.7%		2.2%	-2.0%	5.4%
	Sample	35	28	35	36	31						26		24	26	24
Grass Roots	Mean	13.6% (21.6%)	-3% (14.6%)	7.8% (11.5%)	-0.4% (11.1%)	6.9% (7.2%)						10% (18.6%)		6.3% (11%)	-4.5% (16.4%)	
	Median	9.0%	-2.2%	4.6%	-0.2%	4.4%						6.0%		2.6%	-7.3%	
	Sample	40	29	37	38	32						22		22	21	

Green shading indicates better performance (the lower is the better). Bold indicates a p<0.1. SGPA, CGPA, PSG, PCG, and PCCF stand for schedule growth of phase arrangement, cost growth of phase arrangement, project schedule growth, project cost growth and project change cost factor respectively.

Table 6.9 Comparison of Performance Outcomes for Detailed Engineering and Procurement (Continued)

Category (Standard Deviation)		Sequential arrangement of two phases w/ concurrency (Pattern 2)					Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor (Pattern 4)					Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor (Pattern 8)				
		SGPA	CGPA	PSG	PCG	PCCF	SGPA	CGPA	PSG	PCG	PCCF	SGPA	CGPA	PSG	PCG	PCCF
Addition	Mean	11.3% (19.8%)	-4.6% (14.2%)	1.4% (10.4%)	-2.7% (14.1%)	6% (6.1%)										
	Median	4.3%	-6.1%	0.0%	-4.2%	3.9%										
	Sample	40	33	40	41	35										
Modernization	Mean	21.2% (26.5%)	-3.6% (7.9%)	8.5% (15.9%)	-1% (9.4%)	5.7% (4.8%)						21% (24%)	-4.1% (14.4%)	5.4% (8.5%)	-0.3% (14.7%)	5.9% (4.6%)
	Median	18.1%	-3.2%	3.8%	-0.6%	4.6%						16.9%	-4.1%	2.4%	-0.3%	5.3%
	Sample	39	35	36	39	36						22	21	21	23	21
$10MM-$50MM	Mean	15.2% (22.7%)	-5.4% (9.4%)	4.1% (14.2%)	-2.8% (11.5%)	5.6% (5.2%)	16% (21.4%)	-4% (10.8%)	4% (15.1%)	-2.4% (11.9%)	4.5% (6.8%)	16.5% (24.8%)		1.8% (10.7%)	-3.1% (14.2%)	
	Median	7.5%	-3.0%	0.0%	-1.5%	4.4%	15.2%	-8.4%	2.6%	0.8%	5.3%	8.7%		0.2%	-1.7%	
	Sample	54	45	49	52	47	21	21	20	21	21	22		21	22	
$50MM-$100MM	Mean	18.9% (24.6%)	-5.3% (11.1%)	5.7% (11.4%)	-1.3% (10.6%)	7.1% (6.2%)										
	Median	18.3%	-4.4%	4.2%	-1.3%	4.9%										
	Sample	28	25	28	30	25										
$100MM-$500MM	Mean	12.8% (22.5%)	0.5% (16.5%)	8% (12.5%)	0.5% (12.8%)	6.3% (7.1%)						13.3% (24.6%)	-3.9% (14.6%)	5.8% (11.9%)	0% (17.2%)	5.1% (4.5%)
	Median	8.7%	-1.6%	4.6%	0.0%	3.3%						6.0%	-4.5%	3.6%	-1.1%	4.4%
	Sample	37	27	36	36	31						24	20	24	24	22

Green-shading indicates the best (better if only two groups exist) performance. Bold indicates a p<0.1. SGPA, CGPA, PSG, PCG, and PCCF stand for schedule growth of phase arrangement, cost growth of phase arrangement, project schedule growth, project cost growth and project change cost factor respectively.

6.2.4 Detailed Engineering and Construction

The purpose of analysis of this combination was to check whether an early start of construction prior to completion of detailed engineering was associated with any duration or performance advantage. Table 6.10 illustrates the phase arrangements that remained for testing.

Table 6.10 Description of Phase Arrangement

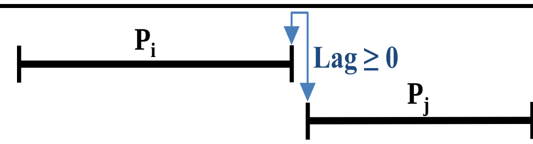
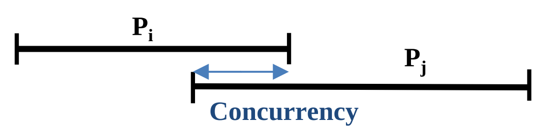
Description of pattern	Phase Arrangement Patterns includes: (P_i : the preceding phase and P_j: the succeeding phase)
Pattern 1: Sequential arrangement of two phases without concurrency: conventional phase arrangement	
Pattern 2: Sequential arrangement of two phases with concurrency	

Table 6.11 demonstrates the analysis results of duration in terms of combined and overall durations. Due to insufficient sample size, project type, grass roots projects, addition projects, projects costing \$50MM-\$100MM, projects costing \$100MM-\$500MM were not included for analysis.

Results demonstrate that projects that utilized pattern 1 had shorter median combined duration with a statistically significant difference at $p<0.1$ in all given categories. For heavy industrial, projects with pattern 1 (78.3 weeks in median) had shorter combined duration than projects with pattern 2 (104.1 weeks), and the difference in median was statistically significant by MWU test (U = 1426.5, z = -3.059, p = 0.002<0.1). In addition, it was observed in light industrial projects that projects with pattern 1 (65.1 weeks in median) had shorter combined duration than projects with pattern 2 (109.1 weeks), and the difference was statistically significant by MWU test (U = 583.5, z = -4.190, p = 0.000<0.1).

It was found that projects that utilized pattern 1 had shorter median overall duration with a statistical significant difference at p<0.1 in projects costing \$10MM-\$50MM. Specifically, projects with pattern 2 had a median overall duration value of 64.5 weeks, compared to projects employing pattern 1 with median value of 84.2 weeks. The difference was statistically significant by MWU test (U = 1528.5, z = -1.867, p = 0.062<0.1). However, this does not indicate that fast-tracking technique was not effective to shorten duration since there was a drastic schedule reduction from combined duration to overall duration. For example, heavy industrial projects had a median of 30 weeks reduction from combined duration (104.1 weeks in median) to overall duration (74.7 weeks).

Corresponding duration factor was also found significant for all industrial projects, heavy industrial projects, and modernization projects. Compared to the other categories, for heavy industrial, projects with pattern 1 had significantly lower median combined duration factor (45.0%) than projects with pattern 2 (50.0%) did by MWU test (U = 1779, z = -1.797, p = 0.072<0.1). Overall duration factor was found to be significantly lower for all industrial, heavy industrial, modernization projects, as well as projects costing \$10MM-\$50MM, but all industrial projects does not fit normality of the data so MWU test was conducted to check the difference in median.

Table 6.12 demonstrates performance outcomes by patterns in the given categories of project characteristics. no statistically significant difference in performance outcomes between projects with different patterns were found in all categories.

Table 6.11 Comparison of Duration for Detailed Engineering and Construction

Category (standard deviation)		Sequential arrangement of two phases w/o concurrency (Pattern 1)				Sequential arrangement of two phases w concurrency (Pattern 2)			
		Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor	Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor
All Industrial Projects	Mean	82.1 (49.3)	**46.6% (10.9%)**	94.1 (52.3)	73% (13.8%)	121.3 (57.1)	49.7% (9.2%)	90.6 (40.5)	66.4% (14.3%)
	Median	**70**	45.3%	86.2	73.8%	108.1	48.9%	81.9	**67.2%**
	Sample	50	50	50	50	281	282	280	282
Heavy Industrial Projects	Mean	86.3 (48.7)	47.1% (11.1%)	101.8 (53.1)	72.8% (13.5%)	122.4 (61.2)	50.2% (9.8%)	89.3 (41.8)	**63.7% (13.5%)**
	Median	**78.3**	**45.0%**	91.7	73.6%	104.1	50.0%	74.7	65.9%
	Sample	27	27	27	27	167	168	166	168
Light Industrial Projects	Mean	77.1 (50.6)	46% (10.9%)	85.1 (51.1)	73.2% (14.5%)	119.8 (50.9)	49% (8.3%)	92.4 (38.6)	70.4% (14.5%)
	Median	**65.1**	45.6%	69.4	75.8%	109.6	47.9%	88	72.7%
	Sample	23	23	23	23	114	114	114	114
Modernization	Mean	82.8 (50.6)	**44% (9.3%)**	95.7 (55.7)	74.1% (14.8%)	112.4 (56.3)	48.6% (9.1%)	83 (39.3)	**65.3% (14.6%)**
	Median	**71.6**	43.7%	82.4	76.2%	94.9	47.8%	73.1	66.2%
	Sample	28	28	28	28	98	98	97	98
\$10MM-\$50MM	Mean	74.4 (42.8)	46% (11%)	89.2 (49.4)	73.6% (14.4%)	90.1 (37.6)	49.2% (10.1%)	71 (31.4)	**64.6% (15%)**
	Median	**59.4**	44.0%	84.2	73.3%	80.9	47.8%	**64.5**	66.0%
	Sample	34	34	34	34	114	114	114	114

Green shading indicates shorter duration or lower duration factor. Bold indicates a $p<0.1$.

Table 6.12 Comparison of Performance Outcomes for Detailed Engineering and Construction

		Sequential arrangement of two phases w/o concurrency (Pattern 1)					Sequential arrangement of two phases w concurrency (Pattern 2)				
		SGPA	CGPA	PSG	PCG	PCCF	SGPA	CGPA	PSG	PCG	PCCF
All Industrial Projects	Mean	7.9% (17.2%)	0.7% (16.6%)	5.4% (12.2%)	-0.8% (13.3%)	5.5% (4.8%)	7.6% (17.5%)	3.2% (19%)	4.8% (12.5%)	-1.4% (13.1%)	5% (6%)
	Median	4.7%	-0.2%	3.0%	-0.4%	5.3%	4.9%	1.9%	1.8%	-1.0%	3.8%
	Sample	49	44	47	49	42	269	251	254	273	226
Heavy Industrial Projects	Mean	8.1% (21.4%)	0.5% (16.6%)	3% (13.1%)	-0.8% (14%)	4.8% (4.6%)	7.4% (19.2%)	2.6% (21.4%)	5.3% (12.4%)	-2.6% (14.3%)	3.9% (5.1%)
	Median	0.0%	0.1%	0.1%	-4.0%	5.3%	3.8%	1.1%	0.8%	-1.7%	3.3%
	Sample	26	22	24	26	20	160	154	154	164	135
Light Industrial Projects	Mean	7.7% (11%)	0.8% (16.9%)	7.8% (10.8%)	-0.8% (12.9%)	6.2% (5%)	7.9% (14.5%)	4.3% (14.6%)	4.2% (12.7%)	0.3% (10.8%)	6.7% (6.8%)
	Median	8.6%	-0.4%	8.5%	0.0%	4.5%	5.8%	2.0%	2.2%	-0.6%	4.8%
	Sample	23	22	23	23	22	109	97	100	109	91
Modernization	Mean	9.1% (15.1%)	1.4% (18.1%)	7.8% (11.1%)	-0.6% (12.6%)	6% (4.3%)	7.7% (16.9%)	5.4% (17.9%)	5.8% (13%)	-0.7% (11.5%)	5.2% (5.7%)
	Median	7.6%	1.6%	5.0%	0.0%	5.4%	5.1%	4.2%	1.7%	0.0%	4.5%
	Sample	27	26	26	27	25	92	93	84	95	83
$10MM-$50MM	Mean	8.1% (19.2%)	-3.4% (14.4%)	4.2% (11.8%)	-4.1% (10.9%)	4.6% (4.5%)	7.6% (17.5%)	1.6% (19.1%)	3.6% (12.8%)	-2.9% (12.7%)	4.7% (6.1%)
	Median	3.1%	-5.4%	2.3%	-4.2%	3.9%	2.0%	2.2%	0.0%	-1.7%	4.3%
	Sample	34	29	32	33	28	107	105	98	112	94

Green shading indicates better performance (the lower is the better). Bold indicates a p<0.1. SGPA, CGPA, PSG, PCG, and PCCF stand for schedule growth of phase arrangement, cost growth of phase arrangement, project schedule growth, project cost growth and project change cost factor respectively.

6.2.5 Procurement and Construction

This section presents analysis that checks whether an early start of construction prior to completion of procurement has any advantage for duration or performance outcomes. Table 6.13 illustrates the phase arrangements used for comparison.

Table 6.13 Description of Phase Arrangement

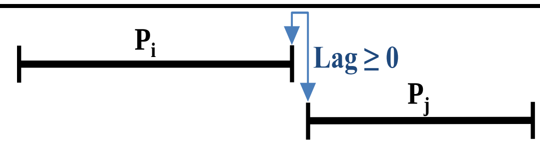
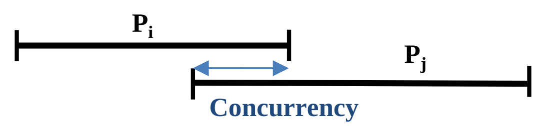
Description of pattern	Phase Arrangement Patterns includes: (P_i : the preceding phase and P_j: the succeeding phase)
Pattern 1: Sequential arrangement of two phases without concurrency: conventional phase arrangement	
Pattern 2: Sequential arrangement of two phases with concurrency	

Table 6.14 demonstrates the result of duration analysis in terms of combined and overall durations. Most industrial projects were somewhat overlapped between procurement and construction as in pattern 2 and consequently the pattern 1 analysis was restricted due to small sample size. Tests for this pattern could only be conducted at the all industrial and heavy industrial projects levels.

Combined duration shows that projects having pattern 1 had shorter duration in median with statistical significance at $p < 0.1$ for given categories of project characteristics. Corresponding duration factor shows that projects having pattern 1 had lower mean duration factor with statistical significance at $p < 0.1$ for given categories. For all industrial projects, projects with pattern 1 shows statistically shorter overall median duration (72.8 weeks), compared to projects with pattern 2 (86.7 weeks) by MWU test (U = 2889, z = -2.152, p = 0.031<0.1). However, no statistical significance of overall duration factor was observed in the categories.

It was observed that projects with pattern 1 had better project schedule growth, while projects with pattern 2 had better project cost growth in Table 6.15. However, no statistical significance was observed for those metrics. Instead, projects with pattern 1 had significantly lower schedule growth of phase arrangement (0.0%), compared to project with patterns 2 (5.3%), the difference in median was statistically significant at $p<0.1$ (U = 2687.5, z = -1.954, p = 0.051<0.1).

Table 6.14 Comparison of Duration for Procurement and Construction

Category (Standard Deviation)		Sequential arrangement of two phases w/o concurrency (Pattern 1)				Sequential arrangement of two phases w concurrency (Pattern 2)			
		Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor	Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor
All Industrial Projects	Mean	64.7 (34)	**41.3% (8.4%)**	76.3 (32.5)	63.4% (16.7%)	132.3 (63.1)	53.6% (9.2%)	91.3 (39.5)	67.3% (15.7%)
	Median	**55.9**	42.0%	**72.8**	61.6%	120.6	54.0%	86.7	68.2%
	N	28	28	28	28	274	274	274	274
Heavy Industrial Projects	Mean	67.9 (37.7)	**40.8% (8.8%)**	80.2 (35.4)	62.4% (16.8%)	130.3 (66.5)	52.2% (9%)	91.3 (40.8)	65.3% (15.4%)
	Median	**57.9**	40.6%	74.4	60.8%	114.6	52.9%	86.4	65.9%
	N	21	21	21	21	166	166	166	166

Green shading indicates shorter duration or lower duration factor. Bold indicates a p<0.1.

Table 6.15 Comparison of Performance Outcomes for Procurement and Construction

Category (Standard Devaiton)		Sequential arrangement of two phases w/o concurrency (Pattern 1)					Sequential arrangement of two phases w concurrency (Pattern 2)				
		SGPA	CGPA	PSG	PCG	PCCF	SGPA	CGPA	PSG	PCG	PCCF
All Industrial Projects	Mean	2.4% (15.6%)	2.6% (16.5%)	4.5% (14.4%)	2.8% (16.1%)	4.8% (5.9%)	8.1% (16.9%)	-1.6% (15.9%)	5.1% (11.6%)	-1.9% (13%)	4.8% (5.4%)
	Median	**0.0%**	2.5%	0.0%	2.3%	4.2%	5.3%	-2.3%	2.4%	-1.4%	3.5%
	N	27	21	27	28	22	258	224	247	264	215
Heavy Industrial Projects	Mean	2.8% (15.4%)		3.5% (14.2%)	0.9% (16%)		8.7% (18%)	-2.5% (17.6%)	5.3% (11.4%)	-3.3% (14.2%)	3.7% (4.3%)
	Median	0.0%		0.0%	3.7%		5.3%	-3.6%	0.9%	-3.1%	3.1%
	N	20		20	21		156	145	150	161	129

Green shading indicates better performance (the lower is the better). Bold indicates a p<0.1. SGPA, CGPA, PSG, PCG, and PCCF stand for schedule growth of phase arrangement, cost growth of phase arrangement, project schedule growth, project cost growth and project change cost factor respectively.

6.2.6 Construction and Startup

This section analyzed whether an early start of startup brought benefits in terms of duration or performance outcomes. Table 6.16 shows the patterns that remained after screening out projects that had fewer than the minimum sample size.

Table 6.16 Description of Phase Arrangement

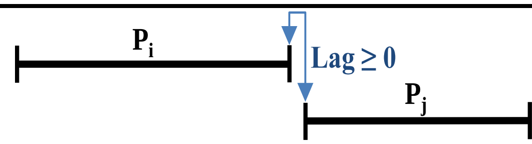
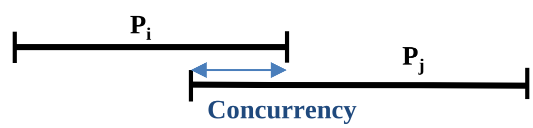
Description of pattern	Phase Arrangement Patterns includes: (P_i : the preceding phase and P_j: the succeeding phase)
Pattern 1: Sequential arrangement of two phases without concurrency: conventional phase arrangement	
Pattern 2: Sequential arrangement of two phases with concurrency	

Table 6.17 demonstrates the result of duration analysis in terms of combined and overall durations. It shows that projects using pattern 1 between construction and startup had shorter duration and lower duration factor in almost all categories, and the difference between projects with pattern 1 and those with pattern 2 are significant at $p<0.1$. Duration factors followed normal distribution in most categories except addition projects, while durations did not follow normal distribution in most categorie,s except projects costing \$100MM-\$500MM.

Table 6.18 summarizes performance outcomes by patterns in the given categories of project characteristics. Results demonstrates that projects with pattern 1 had significantly better median schedule growth of phase arrangement for all industrial projects and projects costing \$10MM-\$50MM, compared to those projects with pattern 2. Projects costing \$10MM-\$50MM with pattern 1 had 0.0% median schedule growth of phase arrangement, while projects with pattern 2 and the same cost range and 7.2% median schedule growth of phase arrangement. The difference in median was statistically significant at $p<0.1$ by the MWU test (U = 958, z = -2.699, p = 0.007<0.1). It was also found that projects with pattern 1 for all industrial projects had better project schedule growth at 0.0%, compared to those projects with pattern 2 at 3.9%, and the difference in median was statistically significant at $p<0.1$ (U = 7232, z = -2.481, p = 0.013<0.1). It was also observed that projects with pattern 1 for projects costing \$100MM-\$500MM had better project cost growth (-2.5%), compared to projects pattern 2 (2.9%), the difference in mean was statistically significant at $p<0.1$ by the independent sample T test (t (89) = -1.796, p = 0.076 < 0.1).

Table 6.17 Comparison of Duration for Construction and Startup

Category (Standard Deviation)		Sequential arrangement of two phases w/o concurrency (Pattern 1)				Sequential arrangement of two phases w concurrency (Pattern 2)			
		Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor	Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor
All Industrial Projects	Mean	61.8 (38.5)	**28.1% (9.9%)**	63.2 (38.5)	**47.1% (18.3%)**	101.2 (48.2)	40.6% (10.3%)	82.2 (37.2)	60.4% (15.5%)
	Median	**52.8**	27.9%	**54**	47.6%	88	39.4%	74.3	60.9%
	N	146	146	146	146	145	146	145	146
Heavy Industrial Projects	Mean	59.5 (36.7)	**27.1% (9.8%)**	60.5 (36.8)	**44.5% (17.8%)**	99.7 (48)	34.3% (7.8%)	82.4 (36.5)	54.2% (13.6%)
	Median	**52.7**	27.5%	**52.9**	45.5%	82.3	33.9%	73.6	55.7%
	N	127	127	127	127	45	45	45	45
Process Projects	Mean	53.6 (28.8)	**27.3% (9.2%)**	54.4 (28.9)	**44.3% (16.7%)**	92.3 (43.4)	35% (8.2%)	74.7 (30.6)	54.4% (13.5%)
	Median	**47.4**	27.2%	**48.9**	44.1%	78.4	34.6%	65.4	56.3%
	N	94	94	94	94	33	33	33	33
Grass Roots	Mean	83.3 (41.6)	**32% (6.6%)**	84.4 (41.2)	**53.3% (12%)**	116.6 (47.8)	42.1% (11.5%)	96.5 (37.3)	62% (15%)
	Median	**73.9**	32.7%	**76.4**	53.5%	103.9	41.7%	89.1	62.6%
	N	37	37	37	37	56	57	56	57
Addition	Mean	61.3 (31.4)	30.7% (8%)	63.6 (31.3)	**52.9% (16.7%)**	84.7 (34.7)	39.3% (9.8%)	71.8 (30.5)	60.8% (12.6%)
	Median	**50.4**	**30.7%**	**54.7**	51.3%	78.5	36.8%	65.4	60.0%
	N	52	52	52	52	44	44	44	44
Modernization	Mean	48.3 (36.7)	**23.2% (11.3%)**	49.2 (36.7)	**37.8% (19.4%)**	98.4 (54.8)	40% (9%)	74.5 (38.2)	58% (18.4%)
	Median	**37.9**	23.5%	**38**	36.7%	77.9	41.3%	70.6	59.8%
	N	57	57	57	57	45	45	45	45
\$10MM-\$50MM	Mean	46.3 (26.7)	**26.9% (11%)**	47.4 (26.8)	**43.7% (20.1%)**	72.2 (26.4)	41.1% (10.3%)	58.5 (19.3)	58.2% (14.9%)
	Median	**41.6**	27.7%	**44**	41.7%	64.9	39.2%	56.3	57.9%
	N	81	81	81	81	47	47	47	47
\$50MM-\$100MM	Mean	68.9 (38.5)	**27.8% (7.7%)**	71.9 (38.2)	**50.9% (16.2%)**	95.9 (40.2)	40.1% (8.8%)	76.8 (30)	59.8% (16.6%)
	Median	**59.5**	27.5%	64.1	53.1%	91.3	38.7%	75.6	58.4%
	N	26	26	26	26	39	39	39	39
\$100MM-\$500MM	Mean	89.3 (43.3)	**30.7% (8.5%)**	**90.3 (42.9)**	**51.7% (14.2%)**	127.9 (52.4)	40.5% (11.3%)	104.5 (39.7)	62.6% (15.1%)
	Median	**82.1**	31.9%	**82.6**	51.2%	117.7	40.2%	100	65.7%
	N	39	39	39	39	59	60	59	60

Green-shading indicates shorter duration or lower duration factor. Bold indicates a $p<0.1$.

Table 6.18 Comparison of Performance Outcomes for Construction and Startup

Category (Standard Deviation)		Sequential arrangement of two phases w/o concurrency (Pattern 1)					Sequential arrangement of two phases w concurrency (Pattern 2)				
		SGPA	CGPA	PSG	PCG	PCCF	SGPA	CGPA	PSG	PCG	PCCF
All Industrial Projects	Mean	5.3% (22.8%)	3.1% (25.4%)	3.4% (11.4%)	-3.4% (14%)	5.2% (5.4%)	9.5% (19.5%)	1.3% (19%)	6.4% (12.7%)	-0.3% (12%)	5.1% (5.9%)
	Median	**0.0%**	3.1%	**0.0%**	-3.1%	4.5%	5.3%	0.1%	3.9%	-0.4%	4.1%
	N	119	91	131	141	111	136	103	134	140	118
Heavy Industrial Projects	Mean	4.4% (21.2%)	2.1% (26.8%)	3.9% (11.4%)	-4.1% (13.9%)	4.5% (4.8%)	9.5% (18.6%)	-1.6% (23.7%)	7% (11.9%)	-0.6% (13.7%)	3.2% (5.3%)
	Median	0.0%	0.3%	0.0%	-3.9%	3.5%	6.6%	-1.4%	3.3%	-0.2%	3.8%
	N	104	76	117	123	96	41	31	42	44	36
Process Projects	Mean	1.8% (20.8%)	2.9% (27.2%)	3.3% (11.2%)	-3.7% (13.5%)	4.8% (5.2%)	8.7% (16.3%)	-5.4% (22%)	5.8% (10.6%)	-2.1% (12.8%)	3.3% (5.4%)
	Median	0.0%	0.0%	0.0%	-4.4%	3.5%	6.6%	-4.6%	2.4%	-0.5%	4.0%
	N	74	57	85	92	73	31	23	31	33	26
Grass Roots	Mean	4.4% (21.2%)	-2.6% (25.5%)	2.9% (11.8%)	-3.7% (16.7%)	5.4% (6.5%)	12.6% (20.5%)	1.3% (22.9%)	6.7% (12%)	0.4% (12.6%)	4.1% (6%)
	Median	1.7%	0.0%	0.9%	-3.3%	3.1%	7.4%	-1.5%	4.1%	-0.5%	4.0%
	N	33	25	34	35	23	53	38	53	55	44
Addition	Mean	4% (21%)	2.5% (20.6%)	2.7% (11.6%)	-4.3% (14.5%)	5.4% (5.5%)	4.2% (13.4%)	1.7% (14.2%)	3.1% (11.8%)	-0.3% (11.5%)	4.9% (5.9%)
	Median	0.0%	5.1%	0.0%	-2.6%	4.7%	0.4%	1.1%	0.5%	-0.6%	3.1%
	N	46	33	49	51	42	40	29	39	42	34
Modernization	Mean	7.7% (26.1%)	7.9% (29.1%)	4.4% (11.1%)	-2.4% (11.7%)	5% (4.8%)	10.7% (22.2%)	1.1% (18.3%)	9.2% (13.9%)	-1.3% (12%)	6.5% (5.6%)
	Median	0.0%	9.4%	0.1%	-2.9%	4.5%	4.2%	0.0%	5.0%	0.0%	5.6%
	N	40	33	48	55	46	43	36	42	43	40
$10MM-$50MM	Mean	2.7% (21%)	2.5% (25.2%)	2.7% (11.3%)	-3.7% (12.6%)	5.1% (5.2%)	11.1% (21.1%)	-2.1% (16.1%)	5.4% (14.1%)	-2.8% (11.3%)	4.8% (6.2%)
	Median	**0.0%**	2.5%	0.0%	-3.5%	5.3%	7.2%	-1.1%	4.1%	-0.6%	4.3%
	N	60	46	71	78	63	46	36	44	47	41
$50MM-$100MM	Mean	11.7% (22.5%)		4.5% (12.4%)	-3.8% (17.9%)	5.9% (6.6%)	3.7% (14.3%)	-0.8% (13.6%)	5.7% (9.3%)	-1.8% (9%)	5.6% (5.6%)
	Median	6.0%		1.4%	-1.8%	4.3%	0.0%	-1.4%	1.8%	0.0%	4.0%
	N	24		24	26	22	38	29	37	39	32

Green shading indicates better performance (the lower is the better). Bold indicates a p<0.1. SGPA, CGPA, PSG, PCG, and PCCF stand for schedule growth of phase arrangement, cost growth of phase arrangement, project schedule growth, project cost growth and project change cost factor respectively.

Table 6.18 Comparison of Performance Outcomes for Construction and Startup (Continued)

Category (Standard Deviation)		Sequential arrangement of two phases w/o concurrency (Pattern 1)					Sequential arrangement of two phases w concurrency (Pattern 2)				
		SGPA	CGPA	PSG	PCG	PCCF	SGPA	CGPA	PSG	PCG	PCCF
$100MM-$500MM	Mean	5.5% (25.5%)	5.7% (23.5%)	3.9% (11.3%)	**-2.5% (14.1%)**	4.9% (4.8%)	12.4% (20.6%)	6.3% (23.9%)	7.8% (13.5%)	2.9% (13.8%)	5.1% (5.8%)
	Median	1.7%	5.3%	2.4%	-3.2%	3.4%	7.1%	1.6%	4.4%	0.1%	3.0%
	N	35	27	36	37	26	52	38	53	54	45

Green-shading indicates the best (better if only two groups exist) performance. Bold indicates a p<0.1. SGPA, CGPA, PSG, PCG, and PCCF stand for schedule growth of phase arrangement, cost growth of phase arrangement, project schedule growth, project cost growth and project change cost factor respectively.

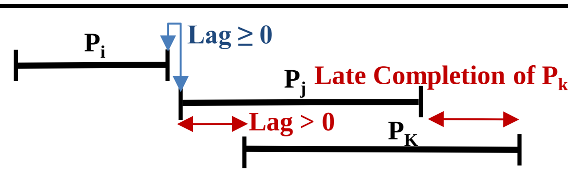
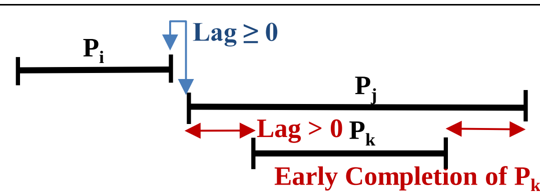
6.3 TRIPLE WISE PHASE ARRANGEMENT

In Chapter 5, the prioritized 15 triple-wise phase arrangements were presented for the three combinations of phases: 1) front-end planning-detailed engineering-procurement; 2) detailed engineering-procurement-construction; 3) procurement-construction-startup. This section is organized by those phase combinations, along with metric scores reflecting the impact of the phase arrangement on duration and performance outcomes.

6.3.1 Front-End Planning, Detailed Engineering, and Procurement

It was found that patterns 2 and 3 were the most common patterns in the combination of front-end planning, detailed engineering, and procurement. The only difference between them was how engineering and procurement were connected. Pattern 2, as shown in Table 6.19, had sequential arrangement with some extent of concurrency, whereas, pattern 3 had parallel arrangement between them.

Table 6.19 Description of Triple Wise Phase Arrangement

<table>
<tr><td>Description of pattern
(combination of patterns, rank)</td><td>Phase Arrangement Patterns includes:
(P_i :the first phase, P_j: the interim phase, and P_k: the last phase</td></tr>
<tr><td>Pattern 2 (1-1-2, 4):
Sequential arrangement w/o concurrency on Pi-Pj and on Pi-Pk;
Sequential arrangement w/ concurrency on Pj and Pk</td><td>
</td></tr>
<tr><td>Pattern 3 (1-1-4, 13):
Sequential arrangement w/o concurrency on Pi-Pj and on Pi-Pk;
Parallel arrangement on Pj and Pk</td><td>
</td></tr>
</table>

Due to small sample size in most categories, comparisons were conducted only at all industrial and heavy industrial projects level. Results show that projects employing pattern 2 had a statistically significant duration advantage for all industrial projects. For all industrial projects, projects with pattern 2 had significantly shorter median overall duration (104.9 weeks), compared to projects with pattern 2 (152.1 weeks), the difference in median was statistically significant at $p<0.1$ by the MWU test (U = 658, z = -1.736, p = 0.083 < 0.1). However, heavy industrial projects had this advantage, but the difference is not statistically significant at $p<0.1$, as shown in Table 6.20.

Table 6.21 presents the analysis results of performance outcomes. Due to small sample size, the comparisons were performed only at all industrial and heavy industrial projects. No statistically significant difference in performance outcomes between two patterns was found.

Table 6.20 Comparison of Duration for Front-End Planning-Detailed Engineering-Procurement

Category (Standard Deviation)		Pattern 2 (1-1-2)				Pattern 3 (1-1-4)			
		Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor	Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor
All Industrial Projects	Mean	146.2 (64.2)	**62% (13.9%)**	116.5 (54.2)	**77.3% (14.9%)**	187.5 (83)	69.5% (8.2%)	145.2 (68.8)	80.6% (11.1%)
	Median	140.4	63.8%	**104.9**	81.9%	191.1	70.4%	152.1	79.6%
	N	78	79	79	79	22	22	22	22
Heavy Industrial Projects	Mean	159.3 (68.7)	71.2% (11.9%)	127.3 (60.4)	82.6% (11.8%)	181.2 (84.6)	70.3% (7%)	139.5 (68.9)	81.9% (10%)
	Median	149	71.2%	105.3	85.5%	168.8	70.4%	137.9	79.6%
	N	35	36	36	36	20	20	20	20

Green-shading indicates shorter duration or lower duration factor. Bold indicates a p<0.1.

Table 6.21 Comparison of Performance Outcomes for Front-End Planning-Detailed Engineering-Procurement

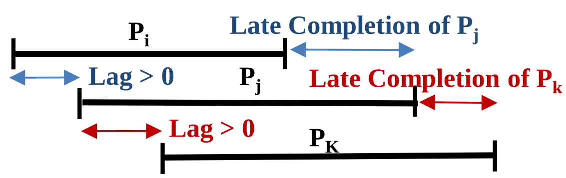
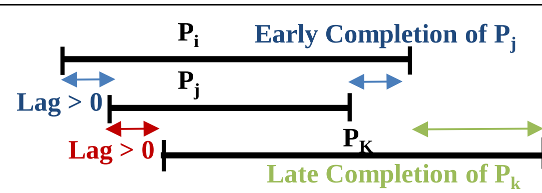
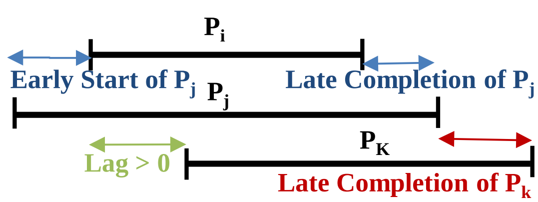
Category (Standard Deviation)		Pattern 2 (1-1-2)					Pattern 3 (1-1-4)				
		SGPA	CGPA	PSG	PCG	PCCF	SGPA	CGPA	PSG	PCG	PCCF
All Industrial Projects	Mean	8.2% (15.2%)	-0.8% (13.6%)	5.5% (11.5%)	-0.6% (12%)	6.1% (6.4%)	6% (12.5%)		5.1% (15.1%)	-1.7% (8.6%)	5.8% (6.8%)
	Median	6.0%	-1.6%	2.1%	-0.4%	3.9%	8.6%		2.3%	-0.2%	5.3%
	N	71	60	70	74	63	21		22	22	21
Heavy Industrial Projects	Mean	6.6% (13.8%)	-5.4% (10.8%)	4.1% (11.7%)	-3.6% (13%)	4.5% (3.9%)			5.3% (15.9%)	-1.7% (8.9%)	
	Median	3.4%	-5.5%	0.1%	-4.9%	3.8%			2.3%	-0.2%	
	N	32	30	32	33	28			20	20	

Green shading indicates better performance (the lower is the better). Bold indicates a p<0.1. SGPA, CGPA, PSG, PCG, and PCCF stand for schedule growth of phase arrangement, cost growth of phase arrangement, project schedule growth, project cost growth and project change cost factor respectively.

6.3.2 Detailed Engineering, Procurement, and Construction

After screening out patterns that had fewer than the required minimum sample size, only three remained for the combination of detailed engineering, procurement, and construction, as shown in Table 6.22. The common feature among those patterns is that engineering and construction share a certain level of concurrency. On the other hand, the difference is related to the relative position and duration of procurement.

Table 6.22 Description of Triple Wise Phase Arrangement

Description of pattern (combination of patterns, rank)	Phase Arrangement Patterns includes: (P_i :the first phase, P_j: the interim phase, and P_k: the last phase
Pattern 9(2-2-2, 1): Sequential arrangement w/ concurrency on Pi-Pj; Sequential arrangement w/ concurrency on Pi-Pk; Sequential arrangement on Pj-Pk	
Pattern 12 (4-2-2, 6): Parallel arrangement on Pi-Pj w/ early completion of Pj; Sequential arrangement w/ concurrency on Pi-Pk; Sequential arrangement on Pj-Pk	
Pattern 14 (8-2-2, 5): Reversed sequential arrangement on Pi-Pj w/ late completion of Pj; Sequential arrangement w/ concurrency on Pi-Pk; Sequential arrangement w/ concurrency on Pj-Pk	

Due to small sample size, project durations were only tested for all industrial and heavy industrial projects. For all industrial projects, shown in Table 6.23, amongst projects with various patterns median combined durations had a statistically significant difference by the Kruskal-Wallis H test (X^2 (2) = 4.857, p = 0.088 < 0.1), the difference was occurred projects with pattern 14 and projects with pattern 9 (p = 0.028). Median overall duration showed the same results (X^2 (2) = 5.529, p = 0.063 < 0.1). A significant difference for overall duration factors was found at p<0.1 (X^2 (2) = 10.515, p = 0.005 < 0.1), the difference in median was noticed in pattern 12 and pattern 14 (p= 0.044). In addition, mean overall duration factor also had a significant difference amongst groups (F(2,85) = 3.061, p = 0.052 < 0.1), and the significant difference was noticed at pattern 12 and pattern 14 (p=0.04).

Table 6.24 presents the analysis results of performance outcomes. Due to small sample size, the comparisons were performed only at all industrial and heavy industrial projects. No statistically significant difference in performance outcomes between two patterns was found.

Table 6.23 Comparison of Duration for Detailed Engineering-Procurement-Construction

Category (Standard Deviation)		Pattern 9 (2-2-2)				Pattern 12 (4-2-2)				Pattern 14 (8-2-2)			
		Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor	Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor	Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor
All Industrial Projects	Mean	208.6 (92.6)	75.7% (10.4%)	107.8 (45.9)	71.2% (13.2%)	189.4 (111.1)	73.4% (12%)	98.9 (56.6)	64.5% (15%)	173.7 (63)	77.2% (7.3%)	89.5 (30.3)	75.8% (14.6%)
	Median	**191.1**	78.0%	**99.5**	71.5%	157.9	72.4%	78	**66.7%**	**167.3**	77.8%	**87.2**	**77.5%**
	N	78	78	78	78	31	31	31	31	46	48	46	48
Heavy Industrial Projects	Mean	220.1 (109.3)	76.3% (12.1%)	112.3 (50.1)	68.5% (13.5%)	192.4 (115.4)	74.5% (12.8%)	97.4 (56.4)	**63.6% (15.2%)**	172.8 (61.6)	77.3% (7.5%)	89.4 (30.7)	**73.2% (14%)**
	Median	206.1	80.0%	104.3	69.5%	157.9	78.7%	78	66.4%	166.9	78.1%	86.3	73.3%
	N	34	34	34	34	25	25	25	25	27	29	27	29
Process Projects	Mean	188.7 (96.7)	75% (11.4%)	96.9 (43.4)	67.4% (13.1%)					175.2 (58.7)	77.2% (7.8%)	91 (28.2)	73% (14.2%)
	Median	155	78.4%	87.1	69.4%					167.6	77.9%	87	72.3%
	N	25	25	25	25					23	23	23	23

Green-shading indicates shorter duration or lower duration factor. Bold indicates a $p<0.1$: note that two, or more than 2 bolds in the same metric and category indicate duration, or duration factor, of a group is significantly different from each other, or among others in post-hoc test.

Table 6.24 Comparison of Performance Outcomes for Detailed Engineering-Procurement-Construction

Category (Standard Deviation)		Pattern 9 (2-2-2)					Pattern 12 (4-2-2)					Pattern 14 (8-2-2)				
		SGPA	CGPA	PSG	PCG	PCCF	SGPA	CGPA	PSG	PCG	PCCF	SGPA	CGPA	PSG	PCG	PCCF
All Industrial Projects	Mean	10.4% (18.5%)	-0.4% (15%)	6% (11.5%)	-1.2% (12.1%)	5.8% (6.5%)	6.8% (19%)	0.6% (12.9%)	2.3% (8.7%)	-0.5% (10.4%)	4.2% (5.9%)	6.9% (15.7%)	-0.9% (16.4%)	4.4% (10.7%)	-3% (16.4%)	3.7% (3%)
	Median	6.7%	0.0%	2.2%	-1.1%	3.7%	5.8%	1.6%	1.2%	0.0%	3.3%	1.3%	0.0%	1.2%	-5.4%	2.9%
	N	77	78	76	72	61	31	31	30	31	30	48	48	46	46	37
Heavy Industrial Projects	Mean	10.2% (18.5%)	-3.1% (20.4%)	3.7% (10.7%)	-6.1% (13.5%)	3.6% (3.4%)	7.4% (20.2%)	0.5% (13.4%)	2.9% (9.1%)	0% (10.8%)	4.7% (5.3%)	7% (13.3%)	-1.2% (19.6%)	6.3% (11.2%)	-3.4% (19.7%)	3.2% (2.5%)
	Median	6.0%	-3.8%	0.0%	-6.5%	3.3%	6.2%	2.6%	1.5%	0.4%	3.8%	2.1%	0.0%	2.4%	-5.3%	2.6%
	Sample	34	34	34	31	26	25	25	24	25	25	29	29	29	27	21
Process Projects	Mean	11.7% (20.9%)	-0.7% (20.2%)	4% (12.3%)	-5.7% (13%)							5.2% (12.3%)	-3.7% (17.4%)	4.2% (8.8%)	-5% (17.2%)	
	Median	5.5%	-4.0%	0.0%	-7.8%							0.4%	-1.8%	2.4%	-5.6%	
	Sample	25	25	25	23							23	23	23	23	

Green shading indicates better performance (the lower is the better). Bold indicates a p<0.1. SGPA, CGPA, PSG, PCG, and PCCF stand for schedule growth of phase arrangement, cost growth of phase arrangement, project schedule growth, project cost growth and project change cost factor respectively.

6.3.3 Procurement, Construction, and Startup

Two patterns were used to measure the impact of phase arrangement on duration and performance outcomes for the combination of procurement, construction, and startup. As shown in Table 6.25 a remarkable difference was noticed for the relative starting time of startup.

Table 6.25 Description of Phase Arrangement

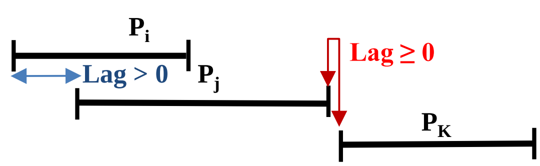
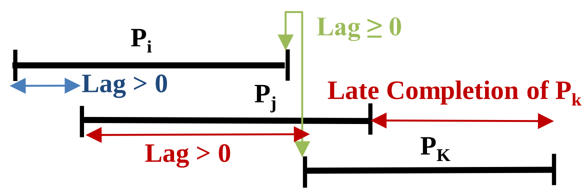
Description of pattern (combination of patterns, rank)	Phase Arrangement Patterns includes: (P_i :the first phase, P_j: the interim phase, and P_k: the last phase
Pattern 6 (2-1-1, 2): Sequential arrangement w/ concurrency on Pi-Pj; Sequential arrangement w/o concurrency on Pi-Pk; Sequential arrangement w/o concurrency on Pj-Pk	
Pattern 7 (2-1-2, 3): Sequential arrangement w/ concurrency on Pi-Pj; Sequential arrangement w/o concurrency on Pi-Pk; Sequential arrangement w/ concurrency on Pj-Pk	

Table 6. 26 demonstrates projects having pattern 6 had shorter duration in terms of combined and overall durations in most categories, Nonetheless, no statistical significance was found in overall duration at $p<0.1$. Table 6.27 shows projects utilizing pattern 6 had the significant difference in project schedule growth and cost growth at $p<0.1$. For project schedule growth, projects having pattern 6 had better median projects schedule growth in all industrial projects and projects costing \$10MM-\$50MM. In addition, those projects had better mean project cost growth in heavy industrial projects, grass roots, and project costing

$100MM-$500MM. All industrial projects had improved median project cost growth in all industrial projects.

Table 6.26 Comparison of Duration for Procurement-Construction-Startup

Category (Standard Deviation)		Pattern 6 (2-1-1)				Pattern 7 (2-1-2)			
		Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor	Comb. Duration (week)	Comb. Duration Factor	Overall Duration (week)	Overall Duration Factor
All Industrial Projects	Mean	130.7 (70.3)	**55.7% (10.1%)**	95 (44.9)	70% (15.3%)	154.5 (62.7)	64.8% (9.6%)	102.4 (40.3)	75.8% (14.5%)
	Median	**115.1**	55.5%	90.8	**69.6%**	140.8	64.1%	94.7	77.0%
	N	112	112	112	112	74	74	73	74
Heavy Industrial Projects	Mean	129.6 (70.3)	54.9% (9.9%)	94.9 (44.5)	**68.9% (15.5%)**	150.2 (58.6)	60.2% (7.7%)	103.1 (40.6)	74.8% (14.1%)
	Median	**114.3**	**55.2%**	90.9	68.8%	136.4	59.9%	95.7	74.9%
	N	99	99	99	99	29	29	29	29
Process Projects	Mean	113.3 (56.2)	**53.8% (10.2%)**	84.5 (35.6)	**67.7% (16.4%)**	130.6 (36.4)	60.8% (8.5%)	91.6 (31.6)	75.5% (13%)
	Median	**103.8**	54.8%	81.7	67.4%	130.6	59.9%	91	74.7%
	N	76	76	76	76	21	21	21	21
Grass Roots	Mean	171.7 (83)	**59% (8.2%)**	118 (49.9)	**71.7% (14.3%)**	178.1 (59.6)	67.2% (10.4%)	118.7 (37.2)	78.8% (13.7%)
	Median	156.3	59.2%	107.9	72.0%	165.9	67.5%	109.4	80.5%
	N	26	26	26	26	35	35	34	35
Addition	Mean	124.6 (63.1)	**56.5% (8.6%)**	90.3 (41)	71% (13%)	135.5 (64.6)	61.8% (8.6%)	88.4 (41.3)	73.3% (14.4%)
	Median	108.4	55.6%	81.7	68.1%	121.6	60.8%	73.6	75.3%
	N	42	42	42	42	21	21	21	21
$10MM-$50MM	Mean	102 (49.8)	**55.1% (10.9%)**	77.4 (36)	**69.6% (16.3%)**	107.6 (33.6)	65% (8.9%)	74.4 (24.9)	76% (13.6%)
	Median	90.9	55.3%	71.2	67.7%	106.6	63.7%	71.6	76.4%
	N	62	62	62	62	23	23	23	23
$100MM-$500MM	Mean	180.9 (68.4)	**57.8% (7.5%)**	126.2 (43.3)	70.9% (11.3%)	188.7 (64.1)	65% (9.2%)	125.6 (39.6)	77.7% (12.6%)
	Median	166.7	58.5%	119.2	**69.6%**	174	65.2%	112.3	77.2%
	N	30	30	30	30	33	33	32	33

Green-shading indicates shorter duration or lower duration factor. Bold indicates a p<0.1.

Table 6.27 Comparison of Performance Outcomes for Procurement-Construction-Startup

Category (Standard Deviation)		Pattern 6 (2-1-1)					Pattern 7 (2-1-2)				
		SGPA	CGPA	PSG	PCG	PCCF	SGPA	CGPA	PSG	PCG	PCCF
All Industrial Projects	Mean	6.4% (18.9%)	-3.9% (17.4%)	3.3% (9.9%)	-4.6% (13.9%)	4.3% (4.4%)	7.8% (15.9%)	1.2% (14.9%)	6.9% (11.9%)	0.8% (12.1%)	4.2% (5.5%)
	Median	0.5%	-5.6%	**0.1%**	**-3.6%**	3.4%	3.8%	-1.4%	3.7%	-0.5%	2.9%
	N	88	64	98	107	82	70	51	70	71	58
Heavy Industrial Projects	Mean	6.5% (18.4%)	-5.4% (17.6%)	3.6% (10.1%)	**-5.7% (13.5%)**	3.8% (3.9%)	6.8% (15.5%)	1.1% (16%)	6.8% (12.9%)	1.4% (13.6%)	3.3% (4.7%)
	Median	0.5%	-5.9%	0.2%	-5.0%	2.9%	1.2%	-1.4%	1.3%	0.7%	3.7%
	N	79	55	90	95	73	28	21	29	29	24
Process Projects	Mean	5.4% (17.6%)	-5% (15.2%)	3% (10.4%)	-5.4% (12.7%)	4.1% (4.1%)	5.1% (15.5%)		4.2% (10.6%)	-0.4% (11.4%)	
	Median	0.5%	-6.6%	0.0%	-5.5%	3.0%	0.0%		0.0%	2.5%	
	N	59	43	69	74	58	21		21	21	
Grass Roots	Mean	6% (16.5%)		4.3% (11.6%)	**-6.8% (16.4%)**		7.3% (16.3%)	4.4% (17.7%)	7% (12.1%)	2.7% (13.9%)	3.4% (5.4%)
	Median	1.6%		2.5%	-5.7%		2.0%	-1.1%	3.1%	0.0%	2.5%
	N	24		24	24		32	21	32	33	25
Addition	Mean	4.2% (17.4%)	-0.8% (18%)	2.5% (9.4%)	-3.7% (14.5%)	4.2% (4.3%)	5% (14.8%)		5% (12.5%)	0% (10.4%)	
	Median	0.3%	0.0%	0.0%	-1.5%	3.5%	2.1%		3.2%	-0.8%	
	N	36	24	38	41	31	20		21	21	
$10MM-$50MM	Mean	4.3% (18.2%)	-2.3% (16.8%)	2.5% (9.5%)	-4.4% (12%)	4.1% (4.6%)	10% (16.3%)		7.1% (11.6%)	-2.9% (9.2%)	4.3% (4.7%)
	Median	0.0%	-2.3%	**0.0%**	-3.9%	3.1%	5.3%		4.9%	-4.0%	4.6%
	N	45	33	53	59	45	23		22	23	20
$100MM-$500MM	Mean	9.4% (21.1%)		4.6% (11%)	**-3.7% (13.4%)**	4.7% (4.4%)	10.4% (17.7%)	7.1% (17.1%)	8.9% (14%)	5% (14.6%)	4% (6%)
	Median	2.0%		2.6%	-3.1%	3.3%	3.9%	0.3%	4.1%	1.7%	2.6%
	N	27		28	28	21	30	23	31	30	24

Green shading indicates better performance (the lower is the better). Bold indicates a $p<0.1$. SGPA, CGPA, PSG, PCG, and PCCF stand for schedule growth of phase arrangement, cost growth of phase arrangement, project schedule growth, project cost growth and project change cost factor respectively.

6.4. SUMMARY AND CONCLUSION

This chapter presented results of analysis that measured the impact of various phase arrangement patterns on duration and performance outcomes. Two types of durations were tested: combined and overall durations, and five performance outcomes were used to examine the patterns further: schedule growth of a phase arrangement, cost growth of a phase arrangement, project schedule growth, project cost growth, and project change cost factor.

The most frequently observed pairwise phase arrangement patterns were sequential with concurrency and sequential without concurrency for the six combination phases: front-end planning-detailed engineering, front-end planning-procurement, detailed engineering-procurement, detailed engineering-construction, procurement-construction, and construction-startup. The text below summarizes the key findings.

- In most combinations of pairwise phases, the sequential phase arrangement without concurrency had a shorter combined duration, or lower combined duration factor. Its counterpart, the sequential phase arrangement with concurrency, on the contrary, had shorter overall duration, or lower overall duration factor. This indicates that projects with an early start of a succeeding phase had longer combined duration and some duration benefits to complete the phases in the given pairwise combinations of phases.
- Overall duration in most combinations of phases, however, had no statically significant difference between two patterns.
- Interestingly, projects with early procurement involvement had shorter overall duration with statistically significant results in median at $p<0.1$ for

all industrial projects, heavy industrial projects, grass roots projects, addition projects, and projects costing $100MM-$500MM.

- In construction and startup, most analysis results showed that projects without concurrency between them had lower combined duration and duration factor in all possible categories, and the difference was statistically significant at $p<0.1$. Moreover, those projects had statistically significant shorter overall duration and lower overall duration factor in most categories except overall duration in projects costing $50MM-$100MM. Based on the ratio of overall duration over combined duration for projects having pattern 2 in all categories, the concurrency between them showed some duration advantages. However, this did not contribute to the duration benefit, compared to behavior of projects having pattern 1 in the combination.
- For projects having early procurement involvement prior to completion of front-end planning, the advantage of better and significant performance outcomes was found at median project change cost factor in heavy industrial projects and process projects at $p<0.1$. Furthermore, all industrial projects, light industrial projects, and modernization projects in median and projects costing $50MM-$100MM in mean tended to have better performance on cost growth of phase arrangement. It was observed that light industrial projects had significantly lower mean project cost growth at $p<0.1$.

In triple-wise phase arrangement patterns, various phase arrangements were considered to examine the impact on duration and performance outcomes. As stated in Chapter 5, more than 80 patterns were identified initially, but the patterns were reduced to

15 patterns after considering the number of cases reported. Due to wide variation of patterns and small proportion of some patterns, sufficient samples to conduct comparisons were not acquired. Despite challenges due to small sample size, the text below summarizes the findings.

- In front-end planning, detailed engineering, and procurement combination, patterns 2 and 3 are the most common patterns. The difference between them was how procurement was shaped. Pattern 2 covers projects having procurement in a sequential arrangement with detailed engineering, with some extent of concurrency. On the other hand, pattern 3 contains projects having procurement in parallel with early completion of it.
- In all industrial projects, median overall duration for projects employing pattern 2 were shown to be statistically and significantly shorter at $p < 0.1$. Heavy industrial projects had shorter durations, but statistically significant difference in durations for both patterns were not found at $p<0.1$. In addition, there was no difference in performance outcomes.
- Patterns 9, 12, and 14 remained for engineering, procurement, construction. The difference in patterns relies on procurement. Pattern 9 has procurement placed sequentially with some extent of concurrency on detailed engineering. Patten 12 contains procurement in parallel, but has early completion with detailed engineering. Pattern 14 has procurement with reversed sequential and late completion after detailed engineering is complete.

- Significant shorter median overall duration was found in all industrial projects with pattern 12 at $p<0.1$. It was also observed that projects with pattern 12 had significant shorter mean overall duration in heavy industrial projects. .
- Lastly, patterns 6 and 7 remained for procurement-construction-startup, meaning that both patterns are common phase arrangements for those phases. The difference between patterns is the starting point of startup. Pattern 6 embraces startup starts after completing preceding phases, while pattern 7 lets startup start before completion of construction.
- Overall durations between patterns were not shown to be statistically significant at $p<0.1$. In addition, no statistical significance at $p<0.1$ was found for performance outcomes.

Caution in interpretation is required because this research was not intended to find a causal relationship between phase arrangements and duration or performance outcomes. It was observed that various phase arrangements had differences in duration or performance, but this does not mean that the patterns cause the difference.

CHAPTER 7: METHODOLOGICAL APPLICATION

7.1 INTRODUCTION

This chapter explains briefly the methodological framework that was created as a result of the dissertation and then illustrates the application of this framework using additional external factors possibly affecting project performance.

7.1.1 Methodological framework

The objectives of this research are to characterize the phase arrangements used by industrial capital projects and to examine quantitatively the impact of the phase arrangements on duration and project performance outcomes. Specifically, this research was designed to analyze capital project schedules to determine the following: 1) how each phase was arranged within the overall schedule; 2) what patterns of phase arrangement exist and which pattern is most common; 3) how various patterns influence duration and performance outcomes. To fulfill the research objective, this research developed the following research questions:

- Research Question 1: How can project development life cycle phase arrangement and duration be quantified by various project characteristics?
- Research Question 2: How can patterns of pairwise/triple-wise phase arrangements be quantified and what are the most common patterns of phase arrangements employed in the project development life cycle?
- Research Question 3: How does each pair/triple of phase arrangements influence their duration and project performance outcomes?

Figure 7.1 illustrates the link of research needs, objectives, and research questions.

Research Needs (Gap)	Research Objectives	Research Questions
Less attention paid to how the phases arranged in the project development life cycle in the quantitative manner	**Characterize** and **quantify** the **phase arrangement** and duration amongst phases of the project development life cycle with the consideration of various project characteristics	**Research Question1:** How can project life cycle phase arrangement and duration be quantified by various project characteristics?
Relationships amongst phases in the project development life cycle were not investigated	**Identify** and **quantify** patterns of **pairwise/triple-wise phase arrangements** employed in phases of the project development life cycle	**Research Question2:** How can patterns of pairwise/triple-wise phase arrangements be quantified and what are the most common patterns of phase arrangements employed in the project development life cycle?
Little information is available about the impact of various phase arrangements on duration and performance	Analyze **impact** of **phase arrangements** on **duration** and **project's performance outcomes**	**Research Question3:** How does each pair/triple of phase arrangements influence their duration and project performance outcomes?

Figure 7.1 Research Needs, Objectives and Questions

The first research question is intended to characterize and quantify phase arrangement of the project development life cycle by analyzing schedule data of industrial capital projects. The phase arrangement was defined as the relative position and sequence of phases in a project development life cycle. In order to define the relative position and sequence of phases, analyzing each phase's duration, its starting time, and finishing time, is essential input. The focal point of data analysis for research question 1 is to see how those five phases were arranged. The second research question aims to identify and quantify patterns of pairwise/triple-wise phase arrangements by grouping two/three phases respectively with consideration of each phase's duration and starting and finishing time. That is, the pairwise phase arrangement represents the relative sequence and duration of the two phases. This research question is also meant to determine the frequency of the patterns employed in the project development life cycle. The last research question is designed to analyze how pairwise/triple-wise phase arrangements influence on duration and performance outcomes under various project characteristics. When the durations of phase arrangements are tested, the focal point of analysis is to determine which phase arrangement had a shortened or lengthened duration. For performance outcomes, which phase arrangement had an improved performance is the point of interest.

7.1.2 Data Source and Application Process

To analyze the project schedule, chemical manufacturing projects and oil-refining projects were selected and categorized as process projects for this research. The sample size is 58 and 53 projects respectively. As an external factor, complexity (measured on a 1 -7 Likert scale) was selected to explain how the research methodological framework can be applied. For this purpose, the complexity was categorized as high (5-7) and low (1-4): Out of 111 selected projects, the mean, standard deviation, and sample size for high complexity projects are 5.67, 0.63, and 38 respectively, while the mean and standard deviation for low complexity are 3.25, 0.98, and 48 respectively. According to CII, low complexity is defined as the use of well established, proven technology, a relatively small number of process steps, a relatively small facility size or process capacity, a facility configuration or geometry that your company has used before, and/or well established, proven construction methods. While, high complexity is defined as the use of new, "unproven" technology, an unusually large number of process steps, large facility size or process capacity, new facility configuration or geometry, and/or new construction methods.

This chapter consists of three primary sections. Section 7.2 presents how phase start time and duration differed from different levels of complexity. Section 7.3 focuses on whether the frequency of patterns of phase arrangements differed base on the level of complexity. Section 7.4 illustrates how the different levels of complexity and phase arrangements influenced duration and performance outcomes. Figure 7.2 illustrates the application process and corresponding hypothesis for each process step.

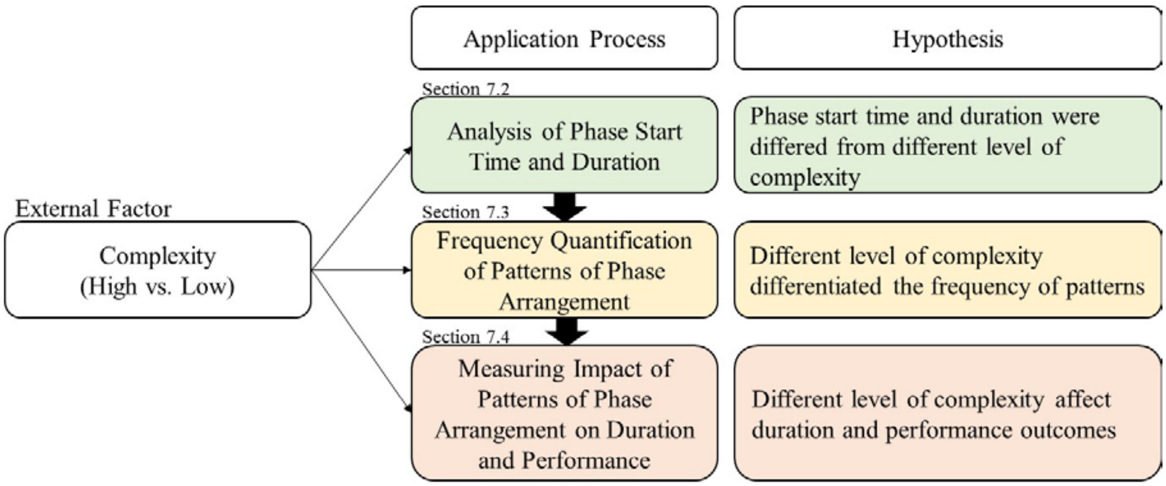


Figure 7.2 Application Process and Corresponding Hypothesis for Each Step

7.2 START TIME AND DURATION OF PHASES

The essential inputs for the project development life cycle phase arrangement are start time and duration of the five phases. Since all the projects were built at various times and had different durations, normalization is required. How to normalize the project schedules was explained in Chpater 3. Therfore, in this section, the analysis focuses on those two inputs of phase arrangement and how different levels of complexity influence phase start time and duration after schedule conversion.

7.2.1 Test of Normality for Phase Starting Time and Duration

To test how different levels of complexity influences phase start time and duration, a normality check is first required because either the T-test or Mann-Whitney *U* test

(MWU) is selected depending on data's normality. Table 7.1 presents results of the normality test for phase start time and duration. For phase start time, data for detailed engineering and construction fit normality, while data for procurement with high complexity and startup did not fit normality based on Shapiro-Wilk test statistics. Even if procurement with low complexity did fit for normality, procurement with high complexity does not fit normality. Therefore, the MWU test is the appropriate method to compare how procurement starting time differs by the level of complexity. For phase duration, procurement and construction are fit data normality, while the remainders do not fit for normality.

Table 7.1 Test Results of Normality for Phase Start Time and Duration

Phase in the project development Cycle		Complexity	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
			Statistic	df	Sig.	Statistic	df	Sig.
Phase Starting Time	Detailed Engineering	High	0.065	38	.200*	0.970	38	0.401
		Low	0.112	48	0.178	0.969	48	0.225
	Procurement	High	0.133	38	0.089	0.928	38	0.018
		Low	0.059	48	.200*	0.984	48	0.769
	Construction	High	0.085	38	.200*	0.983	38	0.817
		Low	0.067	48	.200*	0.988	48	0.897
	Startup	High	0.236	38	0.000	0.798	38	0.000
		Low	0.271	48	0.000	0.608	48	0.000
Phase Duration	Front-End Planning	High	0.123	38	0.159	0.937	38	0.033
		Low	0.070	48	.200*	0.973	48	0.343
	Detailed Engineering	High	0.073	38	.200*	0.989	38	0.960
		Low	0.130	48	0.042	0.939	48	0.014
	Procurement	High	0.108	38	.200*	0.958	38	0.161
		Low	0.109	48	.200*	0.970	48	0.253
	Construction	High	0.107	38	.200*	0.973	38	0.464
		Low	0.104	48	.200*	0.974	48	0.362
	Startup	High	0.272	38	0.000	0.723	38	0.000
		Low	0.281	48	0.000	0.583	48	0.000

Shaded cells indicate non normal distribution of data.

7.2.2 Comparison of Percent Phase Start Time and Duration by Complexity

Tables 7.2 to 7.3 presents the descriptive statistics (mean, standard deviation (SD), median, and sample size (N)) of start time and duration of phases that encompass the project development life cycle. Front-end planning phase was excluded for comparison of phase start time since its percent values by different levels of complexity are the same as zero. Based on the percent mean values of phase start time in Table 7.2, it was found that projects with high complexity started earlier than projects with low complexity. For example, the percent mean value of detailed engineering projects with high complexity (32.3%) started 2.4% earlier than those with low complexity (34.7%). Based on T-test results, however, no statistical significance at $p<0.1$ was observed for start time of detailed engineering and construction between projects with high complexity and projects with low complexity (t (84) = 0.869, p = 0.387>0.1 for detailed engineering; t (84) = -0.335, p = 0.739>0.1 for construction). Based on MWU test results, no statistical significance at $p<0.1$ was observed for start time of procurement and startup (U = 832, z = -0.696, and p=0.487>0.1 for procurement; U = 688, z = -1.950, and p = 0.051>0.1 for startup). The statistical analysis results indicate that different levels of complexity does not differentiate phase start time.

Table 7.2 Comparison of Percent Phase Starting Time for Selected Projects by Complexity

Complexity		Detailed Engineering	Procurement	Construction	Startup
High	Mean (SD)	32.3% (13.6%)	33.8% (19.9%)	54.6% (13.2%)	91.1% (10.6%)
	Median	32.1%	30.8%	53.9%	95.9%
	N	38	38	38	38
Low	Mean (SD)	34.7% (11.7%)	34.2% (15.1%)	55.6% (15.5%)	94.8% (8.5%)
	Median	33.4%	32.8%	57.1%	98.1%
	N	48	48	48	48

SD and N stand for the standard deviation and sample size of the group respectively. Bold indicates the group is statistically significant at $p<0.05$.

Table 7.3 indicates findings showing that projects with high complexity had longer duration in all phases than those with low complexity, based on the percent mean values of phase duration, except duration of front-end planning. Specifically, projects with high complexity had 5.5% longer duration on average on procurement than projects with low complexity. Based on T-test results, however, no statistically significance at $p<0.1$ was observed for projects with high versus low complexity (t (84) = 1.377, p = 0.172>0.1 for procurement; t (84) = 0.031, p = 0.975>0.1 for construction). Based on MWU test results, no statistical significance at $p<0.1$ was observed for duration of front-end planning, detailed engineering, and construction (U = 836, Z = -0.661, and p = 0.509>0.1 for front-end planning; U = 864, z = -0.417, and p = 0.676>0.1 for detailed engineering; U = 798, z = -0.993, and p = 0.320>0.1 for Startup). The statistical analysis results indicate that different levels of complexity do not differentiate phase durations.

Table 7.3 Comparison of Percent Phase Duration for Selected Projects by Complexity

Complexity		Front End Planning	Detailed Engineering	Procurement	Construction	Startup
High	Mean (SD)	33.2% (16.6%)	39.9% (13.1%)	47.3% (18.8%)	41.4% (13.3%)	7.7% (10.8%)
	Median	30.8%	41.4%	50.3%	40.3%	3.3%
	N	38	38	38	38	38
Low	Mean (SD)	34.9% (15.6%)	39.6% (12.3%)	41.8% (18.3%)	41.3% (15.3%)	4.9% (8.5%)
	Median	34.3%	37.1%	37.4%	39.5%	1.9%
	N	48	48	48	48	48

SD and N stand for the standard deviation and sample size of the group. Bold indicates the group is statistically significant at $p<0.05$.

7.3 FREQUENCY OF PHASE ARRANGEMENTS

In Chapter 3, it was illustrated how pairwise and triple-wise phase patterns were constructed. In Chapter 5, the eleven pairwise and fifteen triple-wise phase patterns were identified and their frequencies were quantified. This section illustrates how frequencies of those identified phase patterns differed by level of complexity.

7.3.1 Frequency of Pairwise Phase Pattern

Table 7.4 presents the frequency of the pairwise phase patterns by different level of complexity. The green shading indicates the pattern most frequently utilized and the white color indicates patterns that were rarely used. The frequency is represented as a percent value of the number of projects that used the patterns of the given sample size. As used in Chapter 5, the six phase combinations are shown. Overall, the frequency of each pattern across the six phase combinations for projects with high complexity is similar with that of projects with low complexity. This means that different levels of complexity do not influence the frequency of each pattern across the phase combinations.

As shown in the table, front-end planning and engineering (FEP-ENG) were most frequently connected in pattern 1, the sequential arrangement of two phases without concurrency between two phases, regardless of different level of complexity, followed by pattern 2, the sequential arrangement of two phases with concurrency. Similarly, the same trend appeared on front-end planning and procurement (FEP-PRO); and construction and startup (CON-STARTUP). On the contrary, the engineering and procurement phases (ENG-PRO) were most frequently paired in pattern 2, regardless of the level of complexity. The same trend was noticed in the procurement and construction phases (PRO-CON). Furthermore, the engineering and procurement phases (ENG-PRO) were found to have utilized all possible phase arrangements except pattern 11, the reversed sequential arrangement without concurrency. In detail, for projects with high complexity, the reversed sequential patterns (pattern 8 through pattern 10) were most frquently observed at 36.8%, followed by the sequential patterns (patterns 1 and pattern 2) at 34.2%, and by the parallel patterns (pattern 3 through pattern 7) at 28.9%. Interestingly, for projects with low complexity, the parallel patterns were most frequently observed at 41.7%, followed by the reversed sequential patterns at 33.3%, and by the sequential patterns at 25%. It was noticed that projects with low complexity did not utilize pattern 1 for detailed engineering-procurement.

Table 7.4 Frequency of Pairwise Phase Patterns for Selected Projects by complexity

Pattern	Complexity	Sample Size (N)	FEP-DE	FEP-PRO	DE-PRO	DE-CON	PRO-CON	CON-ST
Pattern1-Sequential arrangement of two phases w/o concurrency	High	38	65.8%	60.5%	10.5%	13.2%	7.9%	63.2%
	Low	48	66.7%	60.4%		4.2%	8.3%	79.2%
Pattern2-Sequential arrangement of two phases w/ concurrency	High	38	31.6%	36.8%	23.7%	84.2%	81.6%	18.4%
	Low	48	33.3%	37.5%	25.0%	93.8%	87.5%	16.7%
Pattern3-Parallel arrangement of two phases w/ exact same stop	High	38	2.6%		2.6%			5.3%
	Low	48			2.1%			
Pattern4-Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor	High	38		2.6%	10.5%			13.2%
	Low	48		2.1%	20.8%			4.2%
Pattern5-Parallel arrangement of two phases with exact same start and longer duration of a successor	High	38			13.2%			
	Low	48			6.3%	2.1%		
Pattern6-Parallel arrangement of two phases with exact same start and stop	High	38			2.6%		2.6%	
	Low	48			4.2%			

Table 7.4 Frequency of Pairwise Phase Patterns for Selected Projects by Complexity (Continued)

Pattern	Complexity	Sample Size (N)	FEP-DE	FEP-PRO	DE-PRO	DE-CON	PRO-CON	CON-ST
Pattern7-Parallel arrangement of two phases with exact same start and longer duration of a predecessor	High	38						
	Low	48			8.3%			
Pattern8-Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor	High	38			15.8%	2.6%	7.9%	
	Low	48			16.7%		4.2%	
Pattern9-Reversed sequential arrangement of two phases w/ concurrency and exact same stop	High	38			5.3%			
	Low	48						
Pattern10-Reversed sequential arrangement of two phases w/ concurrency	High	38			15.8%			
	Low	48			16.7%			
Pattern11-Reversed sequential arrangement of two phases w/o concurrency	High	38						
	Low	48						

7.3.2 Frequency of Triple-wise Phase Pattern

Table 7.5 shows the frequency of the triple-wise phase patterns by different levels of complexity. The method of representing the frequency of patterns is the same as used in Table 7.4. In addition, the three phase combinations are considered as in Chapter 5. As shown in the table, the frequency of the pattern groups across the three phase combinations for projects with high complexity is similar to the one for projects with low complexity. Interestingly, FEP combination for projects with low complexity used fewer for patterns in group 1 and utilized more patterns in group 2, compared to those for projects with high complexity.

Table 7.5 Frequency of Triple-wise Phase Patterns for Selected Projects by Complexity

Pattern	Combination of Patterns	Group of Patterns	High Complexity (N=38)			Low Complexity (N=48)		
			FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)	FEP (FEP-ENG-PRO)	EPC (ENG-PRO-CON)	PCS (PRO-CON-STA)
1	1-1-1	Group 1: Sequential arrangement w/o concurrency between the first and second phases	10.5%	2.6%	7.9%			8.3%
2	1-1-2		18.4%	2.6%		14.6%		
3	1-1-4		10.5%			8.3%		
4	1-1-5		10.5%			6.3%		
5	1-2-8		2.6%	2.6%		6.3%		
6	2-1-1	Group 2: Sequential arrangement w/ concurrency between the first and second phases			50.0%		2.1%	66.7%
7	2-1-2		2.6%	2.6%	10.5%	8.3%	2.1%	12.5%
8	2-1-4				7.9%	4.2%		4.2%
9	2-2-2		2.6%	18.4%	7.9%	2.1%	18.8%	4.2%
10	2-2-4					8.3%		
11	2-2-8		7.9%	2.6%		4.2%	2.1%	
12	4-2-2	Group 3: Other		5.3%			16.7%	
13	5-2-2			10.5%			6.3%	
14	8-2-2			13.2%			16.7%	
15	10-2-2			13.2%			12.5%	
Subtotal of the Group 1			52.6%	7.9%	7.9%	35.4%		8.3%
Subtotal of the Group 2			13.2%	23.7%	76.3%	27.1%	25.0%	87.5%
Subtotal of the Group 3				42.1%			52.1%	
Total			**65.8%**	**73.7%**	**84.2%**	**62.5%**	**77.1%**	**95.8%**

7.4 IMPACT OF PHASE ARRANGEMENT ON DURATION AND PERFORMANCE

In this section, the results of how different phase arrangements influence duration and performance outcomes of capital projects by different level of complexity are presented. Since pattern1 and pattern 2 were primarily used for data analysis in Chapter 6, those two patterns were considered. In addition, three phase combinations were selected: front-end planning and detailed engineering; front-end planning and procurement; and detailed engineering and construction. Due to limited sample size, statistical tests were only conducted for samples greater than 10. Groups with sample size fewer than 10 were not presented. Since the purpose of the test was to find a pattern that had experienced an advantage of duration or performance by level of project complexity, either the t-test or MWU was chosen depending on the data's normality. Bold on mean values in the tables indicates that data for the group and the counterpart fit for normality and t-test was conducted, whereas bold on median indicates that data did not fit for normality and the MWU test was conducted. A series of statistical analyses was conducted to test the following: if different levels of complexity had any advantage on duration and performance within the same pattern; and if different patterns experienced any advantages of duration and performance within the same complexity. Overall duration, project cost growth, project schedule growth, and project change cost factor were considered as output variables in the test. There are myriad factors affecting those outputs, but this research focused and examined whether projects with different levels of complexity and phase arrangements experienced any advantage in duration and performance outcomes. Data points located above and beyond 3 times of IQR (Quartile 3-Quartile 1) were considered as outliers and those points were removed from the analysis.

7.4.1 Front-end Planning and Detailed Engineering (FEP-DE)

Table 7.6 demonstrates the analysis results of duration and performance outcomes by different phase arrangements and different level of complexity. PT1 and PT2 indicates pattern 1 and pattern 2 respectively. Results show that projects that utilized different patterns with the same complexity did not have statistically significant difference on duration and performance outcomes. However, projects having pattern 1 with different level of complexity had statistically significant difference on project schedule growth and project change cost factor at $p<0.1$. In detail, it was observed that projects with high complexity had better median value (-0.6% vs. 0.4%) for project schedule growth and the difference was significant (*U* = 174, *z* = -2.283, *p* = 0.022<0.1). In addition, it was found that projects with low complexity had better project change cost factor (2.0% vs. 3.8%) and the difference was statistically significant (*U* = 182, *z* = -1.814, *p* = 0.070<0.1) by the Mann-Whitney U test.

Table 7.6 Comparison of Duration and Performance by Phase Arrangement and Complexity for FEP-DE

Complexity		Overall Duration (week)		Project Cost Growth		Project Schedule Growth		Project Change Cost Factor	
		PT1	PT2	PT1	PT2	PT1	PT2	PT1	PT2
High	Mean	110.4	100.2	-0.5%	0.8%	-0.7%	1.2%	5.2%	
	S.D.	54.3	33.3	17.3%	17.7%	11.2%	4.2%	5.0%	
	Median	100.3	99.9	-2.6%	0.0%	**-0.6%**	0.0%	3.8%	
	N	25	12	25	12	21	11	23	
Low	Mean	90.3	88.0	-2.6%	-5.6%	2.8%	2.1%	2.8%	3.2%
	S.D.	34.5	35.1	12.5%	11.9%	6.7%	7.2%	3.7%	2.7%
	Median	90.1	90.4	-3.1%	-0.9%	0.4%	0.0%	**2.0%**	2.6%
	N	32	16	32	16	27	14	23	15

SD and N stand for the standard deviation and sample size of the group respectively. Bold in the green colored box indicates the group is statistically significant at p<0.1.

7.4.2 Front-end Planning and Procurement (FEP-PRO)

Table 7.7 presents the analysis results of duration and performance outcomes by different phase arrangements and different levels of complexity for front-end planning and procurement. PT1 and PT2 indicates pattern 1 and pattern 2 respectively. Results show that projects that utilized pattern 2 with high complexity had significantly shorter overall duration and improved project change cost factor at p<0.1. It was also found that projects that used pattern 1 had significantly shorter overall duration when level of complexity was low and that projects that used pattern 1 had significantly better project schedule growth when the level of complexity was high at p<0.1. In detail, t-test results indicate that projects that used pattern 2 had shorter overall duration when the level of complexity was low (97.5 weeks vs. 135.1 weeks) and the difference was statistically significant at p<0.1 (t (35) = 2.239, p = 0.032 < 0.1). It was observed that projects employing pattern 1 with low complexity had shorter overall duration in mean value (96.3 weeks vs. 135.1 weeks) and the difference was statistically significant at p<0.1 (t (50) = 2.286, p = 0.027 < 0.1). MWU test results show that projects that used pattern 1 had better median value of project schedule growth when the level of complexity was high (-0.6% vs. 0.2%) and the difference was statistically significant at p<0.1 (U = 172.5, z = -1.175, p = 0.076 < 0.1). It was found that projects having pattern 2 with high complexity had improved project change cost factor in median (2.4% vs. 4.7%) and the difference was statistically significant at p<0.1 (U = 70.0, z = -1.805, p = 0.071 < 0.1).

Table 7.7 Comparison of Duration and Performance by Phase Arrangement and Complexity for FEP-PRO

Complexity		Overall Duration		Project Cost Growth		Project Schedule Growth		Project Change Cost Factor	
		PT1	PT2	PT1	PT2	PT1	PT2	PT1	PT2
High	Mean	135.1	**97.5**	-1.8%	-1.0%	-0.6%	1.4%	5.7%	2.6%
	S.D.	64.8	37.5	14.3%	16.4%	14.6%	4.1%	5.0%	2.3%
	Median	122.0	95.7	-1.6%	-3.4%	**-0.6%**	0.0%	4.7%	**2.4%**
	N	23	14	22	14	20	14	21	11
Low	Mean	**96.3**	87.4	-4.1%	-1.8%	3.3%	1.8%	4.3%	2.1%
	S.D.	46.9	22.6	10.2%	14.6%	8.5%	5.2%	5.2%	2.2%
	Median	92.0	88.2	-3.1%	0.4%	0.2%	1.5%	3.3%	1.5%
	N	28	18	28	18	25	15	23	14

SD and N stand for the standard deviation and sample size of the group respectively. Bold in the green colored box indicates the group is statistically significant at p<0.1.

7.4.3 Detailed Engineering and Construction (DE-CON)

Table 7.8 presents the analysis results of duration and performance outcomes by different phase arrangements and different levels of complexity for detailed engineering and construction. PT1 and PT2 indicates pattern 1 and pattern 2 respectively. Due to small sample size (N <10), pattern 1 was removed from the analysis. Results show that projects that utilized pattern 2 with different levels of complexity did not have statistically significant difference on project cost growth and project change cost factor. However, it was observed that projects with different levels of complexity had statistically significant difference on overall duration and project schedule growth at p<0.1. In detail, MWU test results show that projects that used pattern 2 had shorter median value of overall duration when the level of complexity was low (67.9 weeks vs. 84.1 weeks) and the difference was statistically significant at p<0.1 (U = 538.0, z = -1.686, p = 0.092 < 0.1). It was found that projects having pattern 2 with high complexity had improved project schedule growth in median (-0.5% vs. 0.3%) and the difference was statistically significant at p<0.1 (U = 400, z = -2.197, p = 0.028 < 0.1).

Table 7.8 Comparison of Duration and Performance by Phase Arrangement and Complexity for DE-CON

Complexity		Overall Duration		Project Cost Growth		Project Schedule Growth		Project Change Cost Factor	
		PT1	PT2	PT1	PT2	PT1	PT2	PT1	PT2
High	Mean		85.4		-0.4%		-1.0%		3.6%
	S.D.		29.6		17.0%		10.2%		3.0%
	Median		84.1		-1.6%		**-0.5%**		3.0%
	N		31		32		29		26
Low	Mean		74.6		-3.6%		2.9%		3.0%
	S.D.		30.0		12.6%		7.7%		3.4%
	Median		**67.9**		-1.7%		0.3%		2.5%
	N		45		45		40		36

SD and N stand for the standard deviation and sample size of the group respectively. Bold in the green colored box indicates the group is statistically significant at p<0.1.

7.5 Summary and Conclusion

This chapter gave a brief explanation of the methodological framework that was used as the backbone of this research and presented how the framework can be applied using this additional factor. Discussion of why the research is needed and its objectives were emphasized. Based on the process defined in Section7.1, this chapter followed each step to illustrate how the framework works under the new external factor as an example of application. The level of complexity was used as a factor, to facilitate simple explanation it was treated as a dichotomy variable (High vs. Low).

Section 7.2 presented the results of phase start time and duration by the different level of complexity. The hypothesis was that phase start time and duration differed by level of complexity. However, it turned out that different level of complexity did not differentiate the phase start time and duration significantly. Section 7.3 illustrated the frequency of phase arrangement patterns under different levels of complexity. The hypothesis was that different levels of complexity would differentiate the frequency of patterns. The application results showed that no considerable variation was observed as pertains to complexity. Section 7.4 demonstrated the impact of complexity and phase arrangement on duration and performance. The hypothesis was that different levels of complexity affect duration and performance outcomes. The test results revealed that statistically significant difference was observed for some metrics for various phase combinations according to different levels of complexity. For example under the FEP-PRO combination, projects with high complexity had significantly improved project schedule growth, compared to the projects with low complexity.

Caution in interpretation is needed because this research was not intended to find a causal relationship. It was observed that different levels of complexity, along with different phase arrangement patterns experienced differences in duration or performance, which does not mean that the complexity or patterns caused the difference.

CHAPTER 8: CONCLUSION

This chapter summarizes the major findings of the research. Each research step was associated with a question that supports the research objectives. The goal of the research was to measure the impact of phase arrangement on duration and other performance outcomes experienced by capital projects. The definition of phase arrangement used in this research is the relative position and sequence of phases that encompass the project's development life cycle. In order to achieve this purpose, this research addressed three questions. Section 8.1 summarizes the objective, process, and findings of each research question, followed by contributions, limitations, and suggestions for future research.

8.1 SUMMARY OF STUDY

8.1.1 Research Question One

The first research question asks, "How can project development life cycle phase arrangement and duration be quantified by various project characteristics?" The objective of the research question was to characterize and quantify phase arrangement of the project development life cycle. The outcomes were illustrated graphically to show how the five phases were arranged in the project development life cycle and to highlight their relative positions, sequences, and duration. In order to reach the outcome, quantification of each phase's start time and duration of the projects was crucial input to characterize phase arrangement. Because of the fact that all the projects collected were built at various times and had different durations, normalization was necessary to convert each phase' starting and finishing times to percent values, reflecting their relative starting and finishing times on project's overall duration. Each phase's starting time and duration were tested to elucidate how various project characteristics influenced upon them. Industry group, project type, nature, and size were used as distinguishing project characteristics. The underlying hypothesis was that there are certain project characteristics that affect either a phase's start time or duration significantly. Among various project characteristics, industry group was revealed to be a major factor, differentiating a phase's start time and duration. Table 7.1 summarizes the project characteristics that influence phases' starting time and duration with statistical significance at $p<0.05$.

Table 8.1 Project Characteristics Influencing Phases' Starting Time and Duration

Project Characteristics	**Phase Start time**	**Phase Duration**
Industry Group	▪ All phases' starting times excepts front-end planning were differentiated by industry group	▪ All phases' durations excepts procurement were differentiated by industry group
Project Type	▪ For heavy industrial projects, project type is a factor differentiating starting time of detailed engineering ▪ For light industrial projects, project type is a factor affecting starting time of procurement and startup.	▪ For heavy industrial projects, project type is a factor differentiating duration of front-end planning ▪ For light industrial projects, project type is a factor affecting duration of procurement and startup
Project Nature	▪ For process projects, project nature was revealed as factor differentiating starting time of construction ▪ For pharmaceutical manufacturing projects, project nature is a factor affecting start time of construction	▪ For process projects, project nature is a factor affecting duration of construction ▪ For pharmaceutical manufacturing projects, project nature is a factor affecting duration of startup
Project Size	▪ For non-process projects, project size is a factor differentiating starting time of construction	▪ For process project, project size is a factor differentiating duration of construction

Based on the quantified analysis of projects and their influential project characteristics, phase arrangements of the project development life cycle were constructed. It was found that the extent of concurrency, on average, was 36.9% of the overall duration between the engineering and procurement phases, followed by 18.9% between the engineering and construction phases. The average percent completion of the engineering phase prior to the construction phase start for industrial projects was 51.6% based on the engineering phase duration. The longest phase was the construction phase (Duration (D) =46.9% with an average start time at (S)=46.7%), followed by the procurement phase (D=46.2% and S=28.7%), and then the engineering phase (D=39.1% and S=26.5%). For heavy industrial projects: the extent of concurrency, on average, was 41% of the overall duration, found between the engineering and procurement phases, followed by 19.7% between the engineering and construction phases. The average percent completion of the engineering phase prior to the construction phase start for industrial projects was 53.5% based on the engineering phase duration. The longest phase was the procurement phase (D =45.3% and S=31.9%), followed by the engineering phase (D=42.34% and S=30.4%), and the construction phase (D=42.32% and S=53.1%) in the overall duration where 0% indicates the project initiation and 100% indicates the project completion. For light industrial projects: the extent of concurrency, on average, was 31.4% of the overall duration between the engineering and procurement phases, followed by 17.8% between the engineering and construction phases. The average percent completion of the engineering phase prior to the construction phase start for industrial projects was 48.6% based on the engineering phase duration. The longest phase was the construction phase (D=53.2% and S=38.8%), followed by the procurement phase (D=47.6% and S=24.2%), and the engineering phase (D=34.6% and S=21%).

8.1.2 Research Question Two

The second research question asks, “How can patterns of pairwise/triple-wise phase arrangements be quantified and what are the most common patterns of phase arrangements employed in the project development life cycle?” The objective of the research question was to identify and quantify patterns of pairwise/triple-wise phase arrangements by grouping two/three relevant phases with consideration of each phases’ duration and starting and finishing times.

In research question one, the relative position and sequence of phases in the project development life cycle was constructed based on the project’s overall duration, with a focus on individual phase starting and ending times to represent their relative positions. However, the phase arrangements only presented the sequential arrangement of two phases with some extent of concurrency. Chapter 3 presented three conceptual phase arrangements: sequential, parallel, and reversed sequential. In order to test whether those conceptual phase arrangements existed in the capital projects data set and to quantify their frequency, the research classified the phase arrangements further with consideration of phases’ starting and finishing times. In detail, the starting times were broken down into early start, the same start, and late start of the succeeding phase. Similarly, the finishing times were broken down into early completion, completion at the same time, and late completion of the succeeding phase. This research investigated 10 possible combinations of pairwise phases to identify patterns. As a result, 11 unique pairwise patterns for capital projects were identified. To quantify their frequency, the six most relevant phase combinations were presented: front-end planning-detailed engineering, front-end planning-procurement, detailed engineering-procurement, detailed engineering-construction, procurement-construction, construction-startup. Amongst those six phase combinations, the most common patterns were pattern 1, sequential arrangement without concurrency, and pattern 2, sequential arrangement with concurrency in most phase combinations. Some interesting findings were obtained, for example, in the engineering-procurement combination pattern 8, the reversed sequential arrangement with concurrency and longer duration of a successor, was found to be the second most common pattern. Moreover, for the construction-startup combination, pattern 1 was the most commonly observed pattern in heavy industrial projects, while pattern 2 was the most common pattern for light industrial projects. Other project characteristics such as project type, nature, project size did not contribute to differentiations in the frequency of patterns.

For identification and quantification of triple-wise phase arrangements, the combination of previously identified pairwise patterns was utilized. In order to quantify the frequency of these patterns, the research selected three phase combinations as follows: 1) FEP: the front-end planning-engineering-procurement phases, 2) EPC: the engineering-procurement-construction phases, and 3) PCS: the procurement-construction-startup phases. Initially, there were eighty-seven patterns identified, but seventy-two patterns had fewer than 15 cases. Finally, 15 patterns that had at least 20 cases were selected. Some observations are discussed below.

For the FEP combination, industrial projects overall present that 46.8% of the projects employed sequential phase arrangement without concurrency between the front-end planning and engineering phases, followed by 23.7% of sequential phase arrangement with concurrency. Even though there was a small discrepancy in the proportions of the project characteristic categories, the ranks were not changed, meaning that project characteristics do not influence it. For the EPC combination, 36.1% of industrial projects overall started procurement before detailed engineering was complete, followed by

33.0% of the projects that used the sequential arrangement with some extent of concurrency between engineering and procurement. In general, heavy industrial projects following the same trend as industrial projects overall, whereas light industrial projects followed the opposite trend. Finally, for the PCS combination, patterns in the sequential arrangement with concurrency between procurement and construction were dominant with 71% in overall industrial projects, 74.9% in heavy industrial projects, and 65.5% in light industrial projects.

8.1.3 Research Question Three

The last question asked, "How does each pair/triple-wise phase arrangement influence duration and project performance outcomes?" The objective was to measure the impacts of this question against various project characteristics.

Two types of duration (or factors) were tested: combined and overall. The combined duration indicates the sum of the durations of each phase used in a phase arrangement. The overall duration is the duration of the phase arrangement and is calculated from the latest phase's end time minus the earliest phase's start time. Duration factor is a percent duration of phase arrangement over combined durations of all phases or overall duration of all phases. Five performance outcomes were tested: schedule growth of phase arrangement, cost growth of phase arrangement, project schedule growth, project cost growth, and project change cost factor. Schedule growth or cost growth of a phase arrangement is intended to measure the schedule or cost deviation from the original planned by various phase arrangements with specific focuses on phases that belong to the phase arrangement. Other performance outcomes test whether various phase arrangements lead to a project's overall schedule, cost, and change cost advantages from what was planned.

The minimum sample size was set as twenty in this research in order to conduct sound statistical analysis. This limited analysis of some categories of project characteristics. As a result, only two project types were presented: process projects and pharmaceutical manufacturing projects. Project nature and project size were examined regardless of industry group and project type.

For most phase combinations, patterns 1 and 2 were the most common. Table 7.2 summarizes findings that showed a statistically significant difference at $p<0.05$ between the two most common patterns with phase combination and categories of project characteristics. There is no pattern for showing the advantage of schedule growth of phase arrangements or project cost growth.

Table 8.2 Impact of Phase Arrangement on Duration and Performance Outcomes

	Pattern 1: sequential arrangement without concurrency	Pattern 2: sequential arrangement with concurrency
Combined Duration	▪ **For front-end planning and detailed engineering:** all industry group, heavy industrial projects, light industrial projects, grass roots projects, and projects costing \$100MM-\$500MM. ▪ **For front-end planning and procurement:** all industrial projects, heavy industrial projects, light industrial projects, process projects, modernization projects, projects costing \$10MM-\$50MM ▪ **For detailed engineering and construction:** all industrial projects, heavy industrial projects, light industrial projects, modernization projects, and projects costing \$10MM-\$50MM ▪ **For procurement and construction:** all industrial projects, and heavy industrial projects	

Table 8.2 Impact of Phase Arrangement on Duration and Performance Outcomes (Continued)

	Pattern 1: sequential arrangement without concurrency	Pattern 2: sequential arrangement with concurrency
Combined Duration	▪ **For construction and startup:** all categories except light industrial projects, and pharmaceutical manufacturing projects	▪
Overall Duration	▪ **For procurement and construction:** all industrial projects ▪ **For construction and startup:** all categories except light industrial projects, pharmaceutical manufacturing projects, and projects costing \$50MM-\$100MM	▪ **For front-end planning and procurement:** all industrial projects, heavy industrial projects, grass roots projects, addition projects, and projects costing \$100MM-\$500MM ▪ **For detailed engineering and construction:** projects costing \$10MM-\$50MM
Combined Duration Factor	▪ **For front-end planning and detailed engineering:** all industrial projects, heavy and light industrial projects, process projects, addition projects, modernization projects, , and projects costing \$10MM-\$50MM and \$100MM-\$500MM ▪ **For front-end planning and procurement:** all categories ▪ **For detailed engineering and construction:** all industrial projects, heavy industrial projects, and modernization projects ▪ **For procurement and construction:** all industrial projects, and heavy industrial projects ▪ **For construction and startup:** all categories except light industrial projects, and pharmaceutical manufacturing projects	
Overall Duration Factor	▪ **For construction and startup:** all categories except light industrial projects, and pharmaceutical manufacturing projects	▪ **For front-end planning and detailed engineering:** projects costing \$50MM-\$100MM ▪ **For detailed engineering and construction:** all industrial projects, heavy industrial projects, modernization projects, projects costing \$10MM-\$50MM

Table 8.2 Impact of Phase Arrangement on Duration and Performance Outcomes (Continued)

	Pattern 1: sequential arrangement without concurrency	Pattern 2: sequential arrangement with concurrency
Schedule Growth of phase Arrangement	▪ **For procurement and Construction:** all industrial projects ▪ **For construction and startup:** all industrial projects, projects costing \$10MM-\$50MM	
Cost Growth of Phase Arrangement	▪ **For construction and startup:** grass roots projects	▪ **For front-end planning and procurement:** all industrial projects, light industrial projects, modernization projects, and projects costing \$50MM-\$100MM
Project Schedule Growth	▪ **For construction and startup:** all industrial projects	
Project Cost Growth	▪ **For construction and startup:** all industrial projects	▪ **For front-end planning and procurement:** light industrial projects
Change Cost Factor		▪ **For front-end planning and procurement:** heavy industrial projects and process projects

In the detailed engineering and procurement combination, projects that employed pattern 4, parallel arrangement, had the lowest and statistically significant mean overall duration in process projects at $p<0.1$ and median overall duration in all industrial projects and heavy industrial projects at $p<0.1$. When comparison was only available for projects having pattern 2 against projects having pattern 8, reversed sequential arrangement, the former projects demonstrated lower mean overall duration factor in light industrial projects, pharmaceutical manufacturing projects, and grass roots projects. In addition, However, there no statistically significant difference in durations was found in projects having different patterns, meaning that those patterns do not contribute to shorter duration at $p<0.1$.

For the front-end planning, detailed engineering, and procurement combination, overall durations for projects employing pattern 2 were shown to be statistically and significantly shorter at $p < 0.1$ for all industrial projects. However, no statistical significance was observed in performance for Projects with pattern 2. For the procurement, construction, and startup combination, median combined duration had a statistically significant difference for all industrial projects, heavy industrial projects, process projects at $p<0.1$. No significance was observed for overall duration in the given categories.

However, caution in interpretation is required because this research was not intended to find a causal relationship between phase arrangements and duration or performance outcomes. With the assumption that no other factors were affecting duration or performance, it was observed that various phase arrangements had the differences in duration or performance, but this does not mean that the patterns cause the difference.

8.2 Research Contribution

While the findings presented in this research were not able to tackle all possible aspects associated with either projects' duration or performance outcomes, it provides several contributions to the body of project management knowledge.

8.2.1 Academic Contribution

The first academic contribution for this research was to characterize phase arrangement to be used as an analytical framework for analyzing project schedule at the phase level. The concept of phase arrangement is to illustrate the relationship amongst phases that encompass the project's development life cycle. It is presented by quantification analysis of phases' components such as starting and finishing times and durations over the projects' overall duration. Conventional belief on project scheduling is that all phases are linked with a finish to start relationship, meaning that phases are sequential rather than concurrent. Typically, there is a certain extent of concurrency between engineering and construction. While analyzing project's phase level schedules, this research demonstrated the quantified extent of concurrency amongst phases and their relative sequences for capital projects.

The second academic contribution for this research was to identify patterns of pairwise/triple wise phase arrangement hidden in the project schedule of the capital projects. Quantification analysis building upon the conceptual phase arrangement revealed a total of 11 unique pairwise and 15 prioritized triple-wise patterns. Some researchers have worked to characterize activity relationships, but their contribution was limited to the relationship of the activities in a sequential manner and to the relationship with some extent of concurrency. Even if four typical relationships between two activities in the critical path method exist, it is hard to define the relationship amongst phases. Instead of defining the relationship, this research provides a structural pattern that can be used to develop a project schedule.

The third academic contribution for this research was to support the impact of pattern on duration. In the combination of front-end planning and detailed engineering and the combination of detailed engineering and construction, two patterns (pattern 1 and pattern 2) were found to be dominant. While projects employing pattern 1 had significantly shorter combined duration, those projects did not have statistically shorter overall durations. This implies that pattern 2, which has sequential arrangement with concurrency, had shown somewhat advantage to shorten the overall duration for projects utilizing pattern 2.

The fourth academic contribution of this research was the finding that early procurement involvement prior to front-end planning was associated with statistically shorter overall duration beyond the impact of concurrency on duration. The more capital projects are fast-tracked to reduce the schedules, the more research efforts are focused on engineering and construction. Typically, procurement has been considered a subsequent phase of front-end planning and engineering in capital projects. However, this research shows that there are some advantages that can be gained in duration and performance outcomes by conducting early procurement involvement.

8.2.2 Practical Contribution

The first practical contribution of this research was associated with the first and second academic contributions and is related to creating project schedule. The traditional approach to developing project schedules has been the “Bottom-Up” method, meaning that defining activities and sequencing them creates a phase-level schedule. On the contrary, this research suggests the benefits of a “Top-Down” approach, based on phase arrangement. By adapting identified patterns of phase arrangement, phase level schedule can be developed. Then typical activities will take their positions. It is obvious that how to develop project schedule based on identified phase arrangement needs more study and is beyond the scope of this research. Nonetheless, this study may provide a certain amount of high level guidance.

The second practical contribution of this research was to open the door for optimized performance through the phase arrangements. Most studies in concurrent engineering focused on the extent of concurrency with respect to rework. The underlying assumption was that increased level of concurrency induces rework or change, resulting in compromised project performance. Nonetheless, there have been little effort to applying the relationship to the phase level schedule. This research may provide a steppingstone to it.

The third practical contribution of this research was related to the last academic contribution that amplifies the importance of early procurement involvement. An earlier study at CII showed that early procurement involvement leads to potential schedule and cost saving. This research supports the findings quantitatively and concluded that early procurement involvement was indeed associated with better project schedule growth and change cost factor when measured at the project level.

8.3 LIMITATION AND FUTURE RESEARCH

Although this research contributes to broaden the body of knowledge regarding phase arrangements and its impact on duration and performance outcomes, it has a few limitations.

The first limitation is the lack of absolute metrics and quality measurement. Even though this research measured the impact of phase arrangement on duration with consideration for various project characteristics, duration itself is very sensitive to change due to crashing, implementation of schedule reduction techniques, scope changes, rework, or delay. The metrics measuring projects' performance used in this research are relative metrics, which compare what is planned versus what is actually performed. Since the targeted projects are industrial projects, analyzing absolute metrics by utilizing variables that can measure capacity such as barrel per day or phase workhours would enrich this research. Moreover, this research explores phase arrangements with focuses on cost and schedule perspectives and with less attention on quality perspectives. Therefore, variables that can measures quality of engineering deliverables would extend the scope of this research.

The second is sample size. More than 300 project data were collected to quantify and analyze project schedules to identify phase arrangement patterns and their impact on duration and performance outcomes. The number of collected project data for this research was not small. When analyses were performed, however, interaction effects of project characteristics' categories such as project nature and project size were not tested due to insufficient sample size. Therefore, a larger sample size will allow researchers to perform possible combinations of interactions to examine impacts of various phase arrangement further. Furthermore, a larger sample size will supply researchers of opportunity to investigate various patterns, rather than sequential patterns.

The third limitation is the data characteristics. This study collected project data that were submitted by CII member companies that are mostly positioned in the top-tier of their businesses in terms of investment and revenue. Moreover, this research collected project data from owners. The project size of the most CII owner companies are large. Therefore, a series of data analyses results that have been shown in this research may not represent the industry accepted norm. Thus, practitioners or project managers should be cautious when interpreting the results.

These limitations provide a good point of departure for future research. As stated in the limitations, this research has dealt with small sample size for some categories and some patterns. A larger sample size will enable to conduct statistical analysis for those that were not included in this research. One of the patterns that was excluded for analysis due to small sample size but remarkable, for example, was the pairwise pattern eleven on detailed engineering and procurement combination. This pattern indicates that procurement starts and completes even before the detailed engineering stats. It represents a somewhat groundbreaking sequence that emphasizes on the strategic sourcing of equipment or items to deliver the capital projects. Another area of future research is to develop project schedule by utilizing identified patterns of phase arrangement. This may become available with the foundational knowledge: this research provided the basis to create project schedule by the "Top-Down" approach; this research supplied the sources for optimized performance through identified phase arrangement patterns. Finally yet importantly, phase arrangement and measure of concurrency become an important consideration in planning and executing capital projects. To achieve faster completion of project without compromised performance, continuous effort to investigate them is required. Measuring the impact of the extent of concurrency on duration or performance through the simulation modeling is one way.

Appendix

Appendix A: Questionnaire (V10.3)

Appendix B: Test of Normality

Appendix A: Questionnaire (V 10.3)

General Project Description
General Information

Your Company Name:____
Your Name: __________________________________
Project Name: ___________________
Project Owner: ____
Primary Designer: ___________________________________
Primary Constructor: ______________________________________
Project Construction Location:
City:_________, (State or Province):_____________, Country: ________________
Lead design office location
City:_________, (State or Province):_____________, Country: ________________
Cost Index City (International Construction Intelligence (previously known as Hanscomb Cost Index) for international projects, and R.S. Means for U.S. and Canada projects)

____

Midpoint of construction (mm/dd/yyyy)

____

Unit Type
☐ Metric (e.g., meter, kilogram, kilometer)
☐ Imperial (e.g., foot, pound, mile)

Primary Currency Used on the Project (e.g., American Dollar, and Euro)

Project Description

Which of the following best describes industry group for this project?

☐Heavy Industrial

☐Chemical Manufacturing
☐Electrical (Generating)
☐Environmental
☐Metals Refining/Processing
☐Mining
☐Tailing
☐Natural Gas Processing
☐Oil/Gas Exploration/Production (well-site)
☐Oil Refining
☐Oil Sands Mining/Extraction
☐Oil Sands SAGD

☐ Light Industrial

☐Automotive Manufacturing
☐Consumer Products Manufacturing
☐Foods
☐Microelectronics Manufacturing
☐Office Products Manufacturing
☐Pharmaceutical Manufacturing
☐Pharmaceutical Labs
☐Pharmaceutical Warehouse
☐Clean Room (Hi-Tech)
☐Other Light Industrial

☐ Oil Sands Upgrading
☐ Cogeneration
☐ Pulp and Paper
☐ Other Heavy Industrial

☐ Buildings
☐ Communications Center
☐ Courthouse
☐ Dormitory/Hotel/Housing/Residential
☐ Embassy
☐ Low rise Office (≤3 floors)
☐ High rise Office (>3 floors)
☐ Hospital
☐ Laboratory
☐ Maintenance Facilities
☐ Movie Theatre
☐ Parking Garage
☐ Physical Fitness Center
☐ Prison
☐ Restaurant/Nightclub
☐ Retail Building
☐ School
☐ Warehouse
☐ Other Buildings

☐ Infrastructure
☐ Airport
☐ Central Utility Plant
☐ Electrical Distribution
☐ Flood Control
☐ Highway (including heavy haul road)
☐ Marine Facilities
☐ Navigation
☐ Process Control
☐ Rail
☐ Tunneling
☐ Water/Wastewater
☐ Telecom, Wide Area Network
☐ Pipeline
☐ Tank farms
☐ Gas Distribution
☐ Other Infrastructure

Project Nature
From the list below, please select the category that best describes the primary nature of this project. Please see the glossary for definitions.
☐ Grass Roots, Greenfield
☐ Brownfield (co-locate)
☐ Modernization, Renovation, Upgrade (changes to existing capacity)
☐ Addition, Expansion
☐ Other Project Nature

Project Priority
Please select the **primary** factor influencing the execution of this project. Assume safety is a given for all projects.
☐ Cost
☐ Schedule
☐ Balanced

Business Driver
Please check all that applied.
☐ Quality
☐ Capacity
☐ Risk
☐ Operability
☐ Environmental
☐ Social
☐ Others

Actual Total Cost of Major Equipment

The purpose of this question is to determine the extent to which the overall project cost and cost performance are driven by the purchase of major equipment. Please see the Equipment Reference Table provided below. Record the total purchase cost of major equipment for this project. **<u>Exclude</u>** costs for field services, bulk construction equipment (such as valves, bus ducts etc.) and off-the-shelf equipment. Project team costs and transportation costs are included.
$______________________
☐ Not Applicable (no major equipment)
☐ Don't Know

Equipment Reference Table	
Examples of Major Equipment	Kinds of Equipment Covered
HVAC Systems	Prefabricated air supply houses
Columns and Pressure Vessels	Towers, columns, reactors, unfired pressure vessels, bulk storage spheres, and unfired kilns; includes internals such as trays and packing.
Tanks	Atmospheric storage tanks, bins, hoppers, and silos.
Exchangers	Heat transfer equipment: tubular exchangers, condensers, evaporators, reboilers, coolers (including fin-fan coolers and cooling towers).
Direct-fired Equipment	Fired heaters, furnaces, boilers, kilns, and dryers, including associated equipment such as super-heaters, air preheaters, burners, stacks, flues, draft fans and drivers, etc.
Pumps	All types of liquid pumps and drivers.
Vacuum Equipment	Mechanical vacuum pumps, ejectors, and other vacuum producing apparatus and integral auxiliary equipment.

Motors	600V and above
Electricity Generation and Transmission	Major electrical items (e.g., unit substations, transformers, switch gear, motor-control centers, batteries, battery chargers, turbines, diesel generators).
Materials-Handling Equipment	Conveyers, cranes, hoists, chutes, feeders, scales and other weighing devices, packaging machines, and lift trucks.
Package Units	Integrated systems bought as a package (e.g., air dryers, air compressors, refrigeration systems, ion exchange systems, etc.).
Special Processing Equipment	Agitators, crushers, pulverizers, blenders, separators, cyclones, filters, centrifuges, mixers, dryers, extruders, fermenters, reactors, pulp and paper, and other such machinery with their drivers.

Turnarounds / Shutdowns / Outages
[Heavy/Light Industrial project only]
Construction performance (cost, schedule, quality) during project turnarounds, shutdowns, and outages may be impacted by schedule demands of the turnaround, shutdown or outage. These turnarounds may be scheduled or unscheduled. Please complete the blocks below to indicate the percentage of total construction work-hours completed during turnaround.

Percent construction during **scheduled turnaround:** ______ %

Percent construction during **unscheduled turnaround:** ______ %

Percent construction during **non-turnaround:** ______ %

Note: the percentages should add up to 100 %

☐ Don’t Know

Project Delivery Method
Please choose the project delivery method from those listed below that most closely characterizes the delivery method used for this project. If more than one delivery method was used, select the primary method.

Delivery Method		Description
☐	Design-Bid-Build	Serial sequence of design and construction phases; Owner contracts separately with designer and constructor.
☐	Design-Build (EPC)	Owner contracts with Design-Build (EPC) contractor.
☐	CM at Risk	Owner contracts with designers and construction manager (CM). CM holds the contracts.
☐	Parallel Primes	Owner contracts separately with designer and multiple prime constructors.

[***If not CM at Risk***] Did you use a Construction Manager not at Risk in conjunction with the selected delivery system?

☐ Yes ☐ No

Project Complexity
Please choose a rating below that best describes the level of complexity for this project, compared to other projects within the same industry sector as this project (e.g., heavy industrial, light industrial, building, infrastructure). Use the definitions below as general guidelines.
Low - Characterized by the use of **well** established, proven technology, a relatively small number of process steps, a relatively small facility size or process capacity, a facility configuration or geometry that your company has used before, well established, proven construction methods.
Average – Characterized by the use of established technology, a moderate number of process steps, a moderate facility size or process capacity, facility configuration or geometry that your company has used before, established, proven construction methods.
High- Characterized by the use of new, "**unproven**" technology, an **unusually** large number of process steps, large facility size or process capacity, new facility configuration or geometry, new construction methods.

Low			Average			High
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

Percent Modularization
Choose a percentage value that best describes the level of modularization (offsite construction) used. This value should be determined as a ratio of the cost of all modules divided by total installed cost. Include all costs for transportation, setting and hooking up field connections.

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
0%	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**

Project Classification
Projects submitted for benchmarking should be representative of the typical project that you execute, i.e., **not impacted by extraordinary factors** that might influence performance or practice use metrics. If the project is not representative, it can still be submitted to be scored, however, please let us know by checking the appropriate box below. Was this project typical or representative of most of the projects that your company performs?
☐ Typical ☐ Not Typical
If project is not typical, please provide a reason:

____
____
____
____
____

Project Scope

Please provide a brief description of the project scope (what is actually being designed / constructed), limit your response to 200 words.

____
____
____
____
____
____
____
____

Project Management Team

Project Management Team (PMT) Size and Participation
Please indicate the peak and average number of participants on the Project Management Team (PMT) during the Front End Planning (FEP) and execution phase of the project. The execution phase of the project is defined to include detail engineering through mechanical completion. To account for individuals responsible for multiple projects, your response should reflect Full Time Equivalents (FTE's). FTE's represent the number of participants and the percent of time each is allocated to the project. For example, if one team member responsible for procurement works ½ time on the project, then the procurement contribution to the FTE measure is 0.5. Likewise, if two project controls specialists work on the team full time, they contribute 2.0 to the FTE. For owners, the participant count should include owner or owner representative members of the PMT, but only those participants whose labor is accounted by the Owner as part of the cost of the project. For contractor, participants don't include craft labors. Typical PMT participants are listed in the table below.

Typical PMT Participants	
Project Manager	Contracting
Engineering Manager / Project Eng.	Project Controls (Cost and Schedule)
Business Manager	QA / QC
Construction Manager	Safety
Operations Manager	Operations
Discipline Engineering Leads	Maintenance
Procurement	Consultants

Project Phase	**PMT Size (FTE's)**	
	Peak	**Average**
Front End Planning		
Design		
Construction		

Union Site Construction Workforce

☐ Union ☐ Non-union jobsite ☐ mixed jobsite

If mixed,_____% Union work force (by work hours)

Engineering Deliverables

Please provide information about this project's use of engineering standards and specifications. Process Industry Practices (PIP) is a consortium of process industry owners and engineering/ construction contractors who serve the industry. PIP publishes “Practices" that reflect standards in many engineering disciplines.

Source of Standards and Specifications

		Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	**NA / UNK**
		0	**1**	**2**	**3**	**4**	
A	The project was executed with internal owner engineering standards and specifications.	☐	☐	☐	☐	☐	☐
B	The project was executed with contractor engineering standards and specifications.	☐	☐	☐	☐	☐	☐
C	The project was executed using industry consortia engineering practices for standards and specifications.	☐	☐	☐	☐	☐	☐
D	The project was executed using Process Industry Practices (PIP) standards and specifications.	☐	☐	☐	☐	☐	☐

Were engineering deliverables released in a timely manner?

Seldom			Sometimes			Always
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

☐ Don’t Know

To what extent were the engineering deliverables complete and accurate (with minimal errors and omissions)?

Seldom Complete and Accurate			Sometimes Complete and Accurate			Always Complete and Accurate
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

☐ Don’t Know

Please provide the number of RFIs issued on this project?

_____________ ☐ Don’t Know

Contract Type

[Owner required section; Contractor please check the contract type for your work scope]
Please indicate below the contract types that were used on this project. If you had multiple contractors for a particular function, please answer the questions below in terms of what was most common.

What was the principal contract type for:

	Lump Sum	Cost Reimbursable (including unit price, Guaranteed Maximum Price)
FEP (or FEED)	☐	☐
Engineering or design	☐	☐
Procurement	☐	☐
Construction	☐	☐
Startup / Commissioning	☐	☐

Project Cost

Budgeted and Actual Project Costs by Function

Please indicate the Budgeted (Baseline) Cost, Contingency, and Actual Project Costs in the table below.

If this project did not include a particular function, please select N/A for Not Applicable.

If you know total project costs but have incomplete function information, you may enter as much function information as you know and override the automatic totaling by manually filling in the total project cost. As long as you don't click back into a function field, your total will be accepted and recorded.

Owner Instructions
Budget amounts include contingency and correspond to funding approved **at time of authorization.** This is the original baseline budget, and should **not be updated** to include any changes since change data are collected in a later section. The total project **budget** amount should include all **planned expenses (excluding** the cost of land**)** from Front-end Planning through startup, including amounts estimated for in-house salaries, overhead, travel, etc. The total **actual** project cost should include all **actual** project costs **(excluding** the cost of land**)** from Front-end Planning through startup, including amounts expended for in-house salaries, overhead, travel, etc.
***Contractor Instructions*: Only enter data for your scope of work**
Only enter cost data for your scope of work. Budget amounts should include contingency and correspond to the estimate **at time of contract award**. This is the original baseline budget, and should **not be updated** to include any changes since change data are collected in a later section.

The total project **budget** amount should be the **planned expenses** of all functions performed by your company, including amounts for in-house salaries, overhead, travel, etc., but excluding the cost of land.
The total **actual** project cost should be the **actual** project costs for functions performed by your company including amounts expended for in-house salaries, overhead, travel, etc., but excluding the cost of land.

Project Cost

Baseline Budget (Including Contingency)	**Amount of Contingency in Budget**	**Actual Cost**
$____________	$____________	$____________

Phase Cost

Project Function	**Baseline Budget (Including Contingency)**	**Amount of Contingency in Budget**	**Actual Cost**
Front-end Planning (or FEED)	$__________________ ☐ NA ☐ Don't Know	$____________ ☐ NA ☐ Don't Know	$__________________ ☐ NA ☐ Don't Know
Detail Engineering	$__________________ ☐ NA ☐ Don't Know	$____________ ☐ NA ☐ Don't Know	$__________________ ☐ NA ☐ Don't Know
Procurement	$__________________ ☐ NA ☐ Don't Know	$____________ ☐ NA ☐ Don't Know	$__________________ ☐ NA ☐ Don't Know
Construction	$__________________ ☐ NA ☐ Don't Know	$____________ ☐ NA ☐ Don't Know	$__________________ ☐ NA ☐ Don't Know
Startup / commissioning	$__________________ ☐ NA ☐ Don't Know	$____________ ☐ NA ☐ Don't Know	$__________________ ☐ NA ☐ Don't Know

Cost of Project Development and Scope Changes

Please record the approved changes to your project by phase in the table provided below. For each phase indicate the net cost impact resulting from approved project development changes and scope changes. Either the owner or contractor may initiate changes.

Project Development Changes include those changes required to execute the original scope of work or obtain original process basis. Scope Changes include changes in the base scope of work or process basis.

For contractors, please only enter data for your scope of work.

Changes should be reported for the time period in which they were initiated. If you can only provide total amounts, please indicate Don't Know in the pre-construction and construction through startup rows and indicate the total amounts in the totals row. As long as you don't click back into a detail information row, your total will be accepted and recorded.

Indicate whether the net impact was a (-) decrease or an (+) increase by indicating a negative number for a decrease and a positive number for an increase. If no change orders were granted during a phase, please enter zero.

Total project change cost: $______________

Change cost by Time period

Time period	**Cost Increase (+) / Decrease (-) of Project Development Changes**	**Cost Increase (+) / Decrease (-) of Scope Changes**	**Change Cost**
Pre-Construction	$____________ ☐ NA ☐ Don't Know	$____________ ☐ NA ☐ Don't Know	$____________ ☐ NA ☐ Don't Know
Construction thru Startup	$____________ ☐ NA ☐ Don't Know	$____________ ☐ NA ☐ Don't Know	$____________ ☐ NA ☐ Don't Know

Direct Cost of Field Rework

If you tracked field rework, indicate the Direct Cost of field rework. The direct cost of field rework relates to all costs needed to perform the rework itself. If there was no direct cost or schedule impact of field rework, please enter "0".

Direct Cost of Field Rework: $________________

Total field rework hours: ______________________________

What was the primary source of rework on this project?

☐ Design
☐ Construction
☐ Suppliers
☐ Owner
☐ Don't Know

Project Schedule

Please indicate your project's Planned Baseline and Actual Project Schedule by function:
If this project did not include a particular function please select N/A.
If you have incomplete function information, you must enter project execution start and stop dates. Please enter as much function information as possible.
Contractor Instruction: please only enter schedule information for your scope of work, excluding FEP from execution schedule.
Owner instruction: execution schedule start from the beginning of Detail Engineering and the end of Start-Up.

Execution Schedule

	Baseline Schedule		**Actual Schedule**	
	Start **mm/dd/yyyy**	Stop **mm/dd/yyyy**	Start **mm/dd/yyyy**	Stop **mm/dd/yyyy**
Execution Schedule	____________ ☐ NA ☐ Don't Know	____________ ☐ NA ☐ Don't Know	____________ ☐ NA ☐ Don't Know	____________ ☐ NA ☐ Don't Know

Schedule by Phase

Project Function	**Baseline Schedule**		**Actual Schedule**	
	Start **mm/dd/yyyy**	Stop **mm/dd/yyyy**	Start **mm/dd/yyyy**	Stop **mm/dd/yyyy**
Front-end Planning (or FED)	____________ ☐ NA ☐ Don't Know	____________ ☐ NA ☐ Don't Know	____________ ☐ NA ☐ Don't Know	____________ ☐ NA ☐ Don't Know
Detail Engineering	____________ ☐ NA ☐ Don't Know	____________ ☐ NA ☐ Don't Know	____________ ☐ NA ☐ Don't Know	____________ ☐ NA ☐ Don't Know

Project Function	Baseline Schedule		Actual Schedule	
	Start **mm/dd/yyyy**	Stop **mm/dd/yyyy**	Start **mm/dd/yyyy**	Stop **mm/dd/yyyy**
Procurement	____________ ☐ NA ☐ Don't Know	____________ ☐ NA ☐ Don't Know	____________ ☐ NA ☐ Don't Know	____________ ☐ NA ☐ Don't Know
Construction	____________ ☐ NA ☐ Don't Know	____________ ☐ NA ☐ Don't Know	____________ ☐ NA ☐ Don't Know	____________ ☐ NA ☐ Don't Know
Startup / Commissioning	____________ ☐ NA ☐ Don't Know	____________ ☐ NA ☐ Don't Know	____________ ☐ NA ☐ Don't Know	____________ ☐ NA ☐ Don't Know

Percent Design Complete

What percentage of the total work hours for detail design was completed prior to total project budget authorization?

____________% ☐ Don't Know

What percentage of the total work hours for detail design was completed prior to start of the construction phase?

____________% ☐ Don't Know

Schedule Disruption

Were there any uncontrollable or unanticipated schedule disruption on this project (this does not include project changes)?

☐ Yes ☐ No ☐ Don't' Know

If yes, what was the total duration in weeks of any uncontrollable or unanticipated schedule disruption?

_____________weeks ☐ Don't Know

Please explain the reason(s) for the schedule disruption(s)

____

____

Schedule Impact of Project Development and Scope Changes

Please record the approved changes to your project by phase in the table provided below. For each phase indicate the net schedule impact resulting from approved project development changes and scope changes. Either the owner or contractor may initiate changes.

Project Development Changes include those changes required to execute the original scope of work or obtain original process basis. Scope Changes include changes in the base scope of work or process basis.

For contractors, please only enter data for your scope of work.

Changes should be reported for the time period in which they were initiated. If you can only provide total amounts, please indicate Don't Know in the pre-construction and construction through startup rows and indicate the total amounts in the totals row. As long as you don't click back into a detail information row, your total will be accepted and recorded.

Indicate whether the net impact was a (-) decrease or an (+) increase by indicating a negative number for a decrease and a positive number for an increase. If no change orders were granted during a phase, please enter zero.

Total schedule impact of change: ____________ (weeks)

Schedule impact of change by time period

Time period	Schedule Increase (+) / Decrease (-) of Project Development Changes (weeks)	Schedule Increase (+) / Decrease (-) of Scope Changes (weeks)	Schedule Change (weeks)
Pre-Construction	______________	______________	______________
Construction thru Startup	______________	______________	______________
Sub-total	______________	______________	

Schedule Impact of Field Rework

If you tracked field rework, indicate the schedule impact in weeks. If there was no schedule impact from field rework, please enter "0".

Schedule impact of Field Rework: _______ (weeks)

Achieving Facility Capacity

[Industrial projects only; not applicable to Pharma] Indicate the primary product or function of the completed facility and the unit of measure which best relates the product or function capacity of the completed facility.

Product or Function	Design Capacity	Unit of Measure

Examples:

Product or Function	*Unit of Measure*
Chemical Products	*Tons/Hour*
Consumer Products	*Cases/Day*

[Building projects only; not applicable to Pharma] Please indicate the size and the unit of measure of the completed building facility

Size	Unit of Measure
	Square Feet / Square Meters

[If contractor did not perform start up activities, skip the rest of this section.]

[Heavy/Light Industrial project only] What percent of initial planned capacities were achieved during Startup?

______% ☐ Don't Know

[Heavy/Light Industrial project only] To what extent were product quality specifications achieved?

Not at All			Moderately			Fully Achieved	Don't Know	NA
1	2	3	4	5	6	7		
☐	☐	☐	☐	☐	☐	☐	☐	☐

To what extent were planned <u>project quality specifications</u> achieved?

Not at All			Moderately			Fully Achieved	Don't Know	NA
1	2	3	4	5	6	7		
☐	☐	☐	☐	☐	☐	☐	☐	☐

Project Outcomes

Using a scale from 1 to 7, where 1 means “not at all successful” and 7 means “extremely successful” please indicate the overall success of this project in the following aspects:

	Not at All Successful		Moderately Successful			Extremely Successful	
	1	2	3	4	5	6	7
Meeting cost expectations	☐	☐	☐	☐	☐	☐	☐
Meeting schedule expectations	☐	☐	☐	☐	☐	☐	☐
Meeting safety expectations	☐	☐	☐	☐	☐	☐	☐
Meeting business objectives	☐	☐	☐	☐	☐	☐	☐
Meeting quality goals	☐	☐	☐	☐	☐	☐	☐

Using a 1 to 7 scale where 1 means “not at all effective” and 7 means “extremely effective”, please indicate how effective the following were on this project:

	Not at All effective		Moderately effective			Extremely effective	
	1	2	3	4	5	6	7
Project teamwork	☐	☐	☐	☐	☐	☐	☐
Project team communications	☐	☐	☐	☐	☐	☐	☐
Your working relationship with the owner / primary contractor	☐	☐	☐	☐	☐	☐	☐
The key project team members understood the owner’s goals and objectives of this project	☐	☐	☐	☐	☐	☐	☐

Projects invariably differ in a variety of ways. Please indicate in the space below what you found to be particular challenges or difficulties on this project, compared to other comparable projects on which you have worked.

____

____

____

What do you think could have improved this project?

____

____

____

____

Workhours and Accident Data

In the spaces below, please record the safety statistics for this project.

Use the U.S. Department of Labor's OSHA definitions for recordable injuries among this project's workers. If you do not track in accordance with these definitions, click Don't Know in the boxes below.

A consolidated project OSHA 300 log is the best source for the data.

Note: for the CM tracking the safety data for the project, please report the safety statistics of the whole project, or skip this section.

Total site work hours __________________ ☐ Don't Know

Total Number of first aids

__________________Cases ☐ Don't Know

Total OSHA Number of Recordable Incident Cases (Injuries, Illnesses, Fatalities, Transfers and Restrictions)

__________________Cases ☐ Don't Know

Total Number of OSHA DART Cases (Days Away, Restricted or Transferred)

__________________Cases ☐ Don't Know

Total Number of Fatality Cases

__________________Cases ☐ Don't Know

Please indicate the number of Workman Compensation Claims on this project.

__________________Cases ☐ Don't Know

Please indicate the total dollar value of Workman Compensation Claims on this project.

__________________Cases ☐ Don't Know

Percentage of Overtime Hours

__________________% ☐ Don't Know

"Overtime" - above 40 work hours a week. For example, if working 55 hours a work, so the overtime is 15 hours and the percentage of overtime hours is calculated as 15 hours overtime / 55 hours worked = 27.3% overtime. If the actual percentage cannot be calculated, please provide your best assessment. Answer Don't Know only if you cannot make a reasonable assessment.

Appendix B: Test for normality

Characterization of Phase Arrangement

1. Phase Start Time

Industrial Group

Category		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Detailed Engineering	Heavy Industrial Projects	0.054	207	.200*	0.991	207	0.212
	Light Industrial Projects	0.129	148	0.000	0.923	148	0.000
Procurement	Heavy Industrial Projects	0.045	207	.200*	0.983	207	0.012
	Light Industrial Projects	0.087	148	0.008	0.957	148	0.000
Construction	Heavy Industrial Projects	0.033	207	.200*	0.994	207	0.634
	Light Industrial Projects	0.087	148	0.008	0.976	148	0.011
Startup	Heavy Industrial Projects	0.192	207	0.000	0.801	207	0.000
	Light Industrial Projects	0.091	148	0.005	0.946	148	0.000

Project Type

Category		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Detailed Engineering	Process Projects	0.055	159	.200*	0.991	159	0.386
	Non-process Projects	0.083	48	.200*	0.985	48	0.781
	Pharmaceutical Manufacturing Projects	0.131	95	0.000	0.919	95	0.000
	Pharmaceutical Laboratory	0.231	25	0.001	0.886	25	0.009
	Other Light Industrial Projects	0.160	28	0.063	0.921	28	0.036
Procurement	Process Projects	0.052	159	.200*	0.981	159	0.025
	Non-process Projects	0.109	48	.200*	0.973	48	0.330
	Pharmaceutical Manufacturing Projects	0.098	95	0.025	0.959	95	0.004
	Pharmaceutical Laboratory	0.154	25	0.129	0.912	25	0.033
	Other Light Industrial Projects	0.120	28	.200*	0.948	28	0.175
Construction	Process Projects	0.048	159	.200*	0.995	159	0.843
	Non-process Projects	0.114	48	0.151	0.953	48	0.052
	Pharmaceutical Manufacturing Projects	0.093	95	0.043	0.981	95	0.182
	Pharmaceutical Laboratory	0.124	25	.200*	0.948	25	0.221
	Other Light Industrial Projects	0.143	28	0.148	0.943	28	0.132
Startup	Process Projects	0.198	159	0.000	0.794	159	0.000
	Non-process Projects	0.180	48	0.000	0.812	48	0.000
	Pharmaceutical Manufacturing Projects	0.093	95	0.040	0.958	95	0.004
	Pharmaceutical Laboratory	0.122	25	.200*	0.964	25	0.505
	Other Light Industrial Projects	0.210	28	0.003	0.817	28	0.000

Project Nature for Process Projects

Category		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Detailed Engineering	Grass roots	0.128	38	0.121	0.979	38	0.683
	Addition	0.095	54	.200*	0.967	54	0.145
	Modernization	0.060	67	.200*	0.990	67	0.875
Procurement	Grass roots	0.116	38	.200*	0.928	38	0.018
	Addition	0.071	54	.200*	0.981	54	0.552
	Modernization	0.116	67	0.026	0.974	67	0.165
Construction	Grass roots	0.070	38	.200*	0.986	38	0.918
	Addition	0.084	54	.200*	0.967	54	0.142
	Modernization	0.064	67	.200*	0.990	67	0.870
Startup	Grass roots	0.144	38	0.045	0.899	38	0.002
	Addition	0.245	54	0.000	0.746	54	0.000
	Modernization	0.230	67	0.000	0.753	67	0.000

Shaded cells indicate non normal distribution of data.

Cost Category for Process Projects

Category		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Detailed Engineering	$10MM-$50MM	0.050	86	.200*	0.988	86	0.613
	$50MM-$100MM	0.087	26	.200*	0.975	26	0.751
	$100MM-$500MM	0.111	47	0.189	0.980	47	0.592
Procurement	$10MM-$50MM	0.049	86	.200*	0.988	86	0.591
	$50MM-$100MM	0.150	26	0.135	0.953	26	0.278
	$100MM-$500MM	0.089	47	.200*	0.911	47	0.002
Construction	$10MM-$50MM	0.109	86	0.014	0.968	86	0.029
	$50MM-$100MM	0.090	26	.200*	0.980	26	0.874
	$100MM-$500MM	0.089	47	.200*	0.954	47	0.064
Startup	$10MM-$50MM	0.209	86	0.000	0.777	86	0.000
	$50MM-$100MM	0.241	26	0.000	0.775	26	0.000
	$100MM-$500MM	0.178	47	0.001	0.808	47	0.000

Project Nature for Pharmaceutical Manufacturing Projects

Category		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Detailed Engineering	Grass roots	0.122	33	.200*	0.945	33	0.093
	Addition	0.165	27	0.057	0.920	27	0.039
	Modernization	0.206	35	0.001	0.868	35	0.001
Procurement	Grass roots	0.123	33	.200*	0.954	33	0.177
	Addition	0.124	27	.200*	0.976	27	0.771
	Modernization	0.160	35	0.024	0.917	35	0.012

Category		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Construction	Grass roots	0.070	33	.200*	0.993	33	0.999
	Addition	0.112	27	.200*	0.978	27	0.810
	Modernization	0.125	35	0.185	0.945	35	0.078
Startup	Grass roots	0.121	33	.200*	0.933	33	0.042
	Addition	0.113	27	.200*	0.927	27	0.058
	Modernization	0.136	35	0.100	0.960	35	0.224

Project Size for Pharmaceutical Manufacturing Projects

Category		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Detailed Engineering	$10MM-$50MM	0.215	29	0.001	0.902	29	0.011
	$50MM-$100MM	0.184	30	0.011	0.823	30	0.000
	$100MM-$500MM	0.070	36	.200*	0.978	36	0.692
Procurement	$10MM-$50MM	0.146	29	0.116	0.948	29	0.162
	$50MM-$100MM	0.151	30	0.078	0.924	30	0.034
	$100MM-$500MM	0.073	36	.200*	0.972	36	0.496
Construction	$10MM-$50MM	0.119	29	.200*	0.949	29	0.168
	$50MM-$100MM	0.152	30	0.076	0.962	30	0.344
	$100MM-$500MM	0.147	36	0.047	0.940	36	0.050
Startup	$10MM-$50MM	0.168	29	0.036	0.912	29	0.019
	$50MM-$100MM	0.126	30	.200*	0.942	30	0.101
	$100MM-$500MM	0.112	36	.200*	0.934	36	0.032

2. Phase Duration

Industrial Group

Category		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Front-End Planning	Heavy Industrial Projects	0.093	207	0.000	0.971	207	0.000
	Light Industrial Projects	0.115	148	0.000	0.906	148	0.000
Detailed Engineering	Heavy Industrial Projects	0.049	207	.200*	0.975	207	0.001
	Light Industrial Projects	0.105	148	0.000	0.957	148	0.000
Procurement	Heavy Industrial Projects	0.041	207	.200*	0.995	207	0.657
	Light Industrial Projects	0.064	148	.200*	0.983	148	0.068
Construction	Heavy Industrial Projects	0.043	207	.200*	0.993	207	0.455
	Light Industrial Projects	0.079	148	0.025	0.991	148	0.459
Startup	Heavy Industrial Projects	0.204	207	0.000	0.780	207	0.000
	Light Industrial Projects	0.096	148	0.002	0.948	148	0.000

Shaded cells indicate non normal distribution of data.

Project Type

Category		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Front-End Planning	Process Projects	0.089	159	0.004	0.980	159	0.018
	Non-process Projects	0.123	48	0.065	0.923	48	0.004
	Pharmaceutical Manufacturing Projects	0.129	95	0.000	0.904	95	0.000
	Pharmaceutical Laboratory	0.261	25	0.000	0.842	25	0.001
	Other Light Industrial Projects	0.130	28	.200*	0.943	28	0.132
Detailed Engineering	Process Projects	0.055	159	.200*	0.972	159	0.003
	Non-process Projects	0.077	48	.200*	0.982	48	0.658
	Pharmaceutical Manufacturing Projects	0.092	95	0.048	0.976	95	0.080
	Pharmaceutical Laboratory	0.173	25	0.052	0.869	25	0.004
	Other Light Industrial Projects	0.165	28	0.050	0.909	28	0.019
Procurement	Process Projects	0.040	159	.200*	0.993	159	0.641
	Non-process Projects	0.067	48	.200*	0.990	48	0.961
	Pharmaceutical Manufacturing Projects	0.081	95	0.141	0.980	95	0.147
	Pharmaceutical Laboratory	0.143	25	.200*	0.945	25	0.190
	Other Light Industrial Projects	0.112	28	.200*	0.940	28	0.112
Construction	Process Projects	0.063	159	.200*	0.989	159	0.223
	Non-process Projects	0.075	48	.200*	0.966	48	0.171
	Pharmaceutical Manufacturing Projects	0.078	95	0.191	0.992	95	0.865
	Pharmaceutical Laboratory	0.136	25	.200*	0.926	25	0.069
	Other Light Industrial Projects	0.136	28	0.198	0.939	28	0.102
Startup	Process Projects	0.217	159	0.000	0.757	159	0.000
	Non-process Projects	0.182	48	0.000	0.824	48	0.000
	Pharmaceutical Manufacturing Projects	0.095	95	0.035	0.959	95	0.005
	Pharmaceutical Laboratory	0.122	25	.200*	0.964	25	0.505
	Other Light Industrial Projects	0.209	28	0.003	0.830	28	0.000

Project Nature for Process Projects

Category		Kolmogorov-Smirnov[a] Statistic	df	Sig.	Shapiro-Wilk Statistic	df	Sig.
Front-End Planning	Grass_roots	0.095	38	.200*	0.973	38	0.493
	Addition	0.099	54	.200*	0.969	54	0.179
	Modernization	0.097	67	0.194	0.972	67	0.127
Detailed Engineering	Grass_roots	0.142	38	0.051	0.892	38	0.002
	Addition	0.083	54	.200*	0.980	54	0.512
	Modernization	0.083	67	.200*	0.977	67	0.249
Procurement	Grass_roots	0.067	38	.200*	0.992	38	0.995
	Addition	0.064	54	.200*	0.991	54	0.960
	Modernization	0.094	67	.200*	0.982	67	0.442
Construction	Grass_roots	0.063	38	.200*	0.988	38	0.949
	Addition	0.124	54	0.037	0.938	54	0.008
	Modernization	0.069	67	.200*	0.988	67	0.768
Startup	Grass_roots	0.147	38	0.037	0.890	38	0.001
	Addition	0.230	54	0.000	0.725	54	0.000
	Modernization	0.268	67	0.000	0.656	67	0.000

Cost Category for Process Projects

Category		Kolmogorov-Smirnov[a] Statistic	df	Sig.	Shapiro-Wilk Statistic	df	Sig.
Front-End Planning	$10MM-$50MM	0.089	86	0.090	0.982	86	0.259
	$50MM-$100MM	0.129	26	.200*	0.902	26	0.017
	$100MM-$500MM	0.112	47	0.178	0.963	47	0.139
Detailed Engineering	$10MM-$50MM	0.074	86	.200*	0.980	86	0.210
	$50MM-$100MM	0.142	26	0.192	0.953	26	0.266
	$100MM-$500MM	0.122	47	0.079	0.923	47	0.004
Procurement	$10MM-$50MM	0.042	86	.200*	0.989	86	0.670
	$50MM-$100MM	0.154	26	0.112	0.931	26	0.082
	$100MM-$500MM	0.064	47	.200*	0.993	47	0.991
Construction	$10MM-$50MM	0.116	86	0.006	0.953	86	0.004
	$50MM-$100MM	0.072	26	.200*	0.977	26	0.800
	$100MM-$500MM	0.061	47	.200*	0.976	47	0.427
Startup	$10MM-$50MM	0.225	86	0.000	0.738	86	0.000
	$50MM-$100MM	0.284	26	0.000	0.719	26	0.000
	$100MM-$500MM	0.179	47	0.001	0.803	47	0.000

Project nature for Pharmaceutical Manufacturing Projects

Category		Kolmogorov-Smirnov[a] Statistic	df	Sig.	Shapiro-Wilk Statistic	df	Sig.
Front-End Planning	Grass_roots	0.097	33	.200*	0.950	33	0.131
	Addition	0.174	27	0.034	0.865	27	0.002
	Modernization	0.189	35	0.003	0.922	35	0.016
Detailed Engineering	Grass_roots	0.105	33	.200*	0.962	33	0.286

Category		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
	Addition	0.178	27	0.029	0.937	27	0.105
	Modernization	0.070	35	.200*	0.982	35	0.836
Procurement	Grass_roots	0.107	33	.200*	0.953	33	0.168
	Addition	0.124	27	.200*	0.946	27	0.167
	Modernization	0.123	35	.200*	0.951	35	0.125
Construction	Grass_roots	0.123	33	.200*	0.982	33	0.841
	Addition	0.155	27	0.097	0.933	27	0.080
	Modernization	0.157	35	0.030	0.961	35	0.252
Startup	Grass_roots	0.119	33	.200*	0.932	33	0.041
	Addition	0.121	27	.200*	0.948	27	0.196
	Modernization	0.115	35	.200*	0.961	35	0.252

Cost Category for Pharmaceutical Manufacturing Projects

Category		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Front-End Planning	$10MM-$50MM	0.125	29	.200*	0.915	29	0.022
	$50MM-$100MM	0.184	30	0.011	0.904	30	0.010
	$100MM-$500MM	0.169	36	0.011	0.842	36	0.000
Detailed Engineering	$10MM-$50MM	0.115	29	.200*	0.948	29	0.163
	$50MM-$100MM	0.081	30	.200*	0.950	30	0.164
	$100MM-$500MM	0.123	36	0.183	0.958	36	0.182
Procurement	$10MM-$50MM	0.097	29	.200*	0.976	29	0.738
	$50MM-$100MM	0.147	30	0.096	0.958	30	0.281
	$100MM-$500MM	0.078	36	.200*	0.978	36	0.679
Construction	$10MM-$50MM	0.095	29	.200*	0.979	29	0.809
	$50MM-$100MM	0.079	30	.200*	0.991	30	0.996
	$100MM-$500MM	0.150	36	0.041	0.937	36	0.041
Startup	$10MM-$50MM	0.161	29	0.053	0.915	29	0.023
	$50MM-$100MM	0.140	30	0.136	0.927	30	0.041
	$100MM-$500MM	0.118	36	.200*	0.943	36	0.062

Analysis of phase Arrangement Impact of Duration and Performance Outcome

1. FEP-DE

1.1 Duration

Category		Sequential arrangement of two phases w/o concurrency (Pattern 1)			Sequential arrangement of two phases w concurrency (Pattern 2)		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
ALL	Combined Duration	0.933	230	0.000	0.913	113	0.000
	Combined Duration Factor	0.991	230	0.189	0.982	115	0.121
	Overall Duration	0.922	230	0.000	0.906	114	0.000
	Overall Duration Factor	0.980	230	0.002	0.977	115	0.045
Heavy Industrial Projects	Combined Duration	0.939	134	0.000	0.897	66	0.000
	Combined Duration Factor	0.986	134	0.207	0.974	68	0.162
	Overall Duration	0.926	134	0.000	0.901	67	0.000
	Overall Duration Factor	0.969	134	0.004	0.957	68	0.020
Light Industrial Projects	Combined Duration	0.930	96	0.000	0.946	47	0.031
	Combined Duration Factor	0.953	96	0.002	0.988	47	0.900
	Overall Duration	0.927	96	0.000	0.938	47	0.015
	Overall Duration Factor	0.985	96	0.335	0.983	47	0.722
Process Projects	Combined Duration	0.911	104	0.000	0.959	52	0.069
	Combined Duration Factor	0.983	104	0.218	0.985	52	0.750
	Overall Duration	0.903	104	0.000	0.975	52	0.355
	Overall Duration Factor	0.951	104	0.001	0.958	52	0.061
Pharmaceutical Manufacturing projects	Combined Duration	0.959	62	0.035	0.954	30	0.210
	Combined Duration Factor	0.962	62	0.052	0.972	30	0.593
	Overall Duration	0.968	62	0.100	0.944	30	0.115
	Overall Duration Factor	0.987	62	0.746	0.978	30	0.778
Grass Roots	Combined Duration	0.943	66	0.004	0.925	34	0.023
	Combined Duration Factor	0.982	66	0.433	0.988	34	0.970
	Overall Duration	0.927	66	0.001	0.945	34	0.086
	Overall Duration Factor	0.986	66	0.685	0.987	34	0.945
Addition	Combined Duration	0.887	80	0.000	0.946	37	0.073
	Combined Duration Factor	0.992	80	0.893	0.992	38	0.993
	Overall Duration	0.866	80	0.000	0.919	37	0.010
	Overall Duration Factor	0.980	80	0.241	0.964	38	0.248
Modification	Combined Duration	0.947	84	0.002	0.939	42	0.027
	Combined Duration Factor	0.986	84	0.496	0.974	43	0.436
	Overall Duration	0.950	84	0.003	0.860	43	0.000
	Overall Duration Factor	0.955	84	0.005	0.953	43	0.079
$10MM-50MM	Combined Duration	0.920	107	0.000	0.976	42	0.522
	Combined Duration Factor	0.985	107	0.277	0.987	43	0.909
	Overall Duration	0.922	107	0.000	0.749	43	0.000
	Overall Duration Factor	0.971	107	0.018	0.964	43	0.189
$50MM-100MM	Combined Duration	0.898	49	0.000	0.829	32	0.000
	Combined Duration Factor	0.977	49	0.449	0.904	32	0.008
	Overall Duration	0.896	49	0.000	0.831	32	0.000
	Overall Duration Factor	0.975	49	0.380	0.986	32	0.948
$100MM-500MM	Combined Duration	0.939	74	0.001	0.950	39	0.085
	Combined Duration Factor	0.982	74	0.358	0.990	40	0.978
	Overall Duration	0.923	74	0.000	0.985	39	0.874
	Overall Duration Factor	0.977	74	0.199	0.965	40	0.243

1.2 Performance

Category		Sequential arrangement of two phases w/o concurrency (Pattern 1)			Sequential arrangement of two phases w concurrency (Pattern 2)		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
ALL	SGPA	0.904291	211	0.00	0.917413	106	0.00
	CGPA	0.957926	182	0.00	0.96342	86	0.02
	PSG	0.93814	207	0.00	0.93263	107	0.00
	PCG	0.963639	222	0.00	0.969492	113	0.01
	PCCF	0.921179	184	0.00	0.949989	94	0.00
Heavy Industrial projects	SGPA	0.903887	120	0.00	0.925875	65	0.00
	CGPA	0.932133	111	0.00	0.97085	56	0.19
	PSG	0.926406	120	0.00	0.901872	65	0.00
	PCG	0.976714	130	0.02	0.967164	68	0.07
	PCCF	0.945664	105	0.00	0.922192	54	0.00
Light Industrial Projects	SGPA	0.907839	91	0.00	0.902202	41	0.00
	CGPA	0.970667	71	0.09	0.912913	30	0.02
	PSG	0.942648	87	0.00	0.9177	42	0.01
	PCG	0.921254	92	0.00	0.989576	45	0.95
	PCCF	0.88696	79	0.00	0.955839	40	0.12
Process Projects	SGPA	0.922758	90	0.00	0.944758	49	0.02
	CGPA	0.954678	85	0.00	0.934766	44	0.02
	PSG	0.953322	91	0.00	0.880708	49	0.00
	PCG	0.976898	102	0.07	0.965009	52	0.13
	PCCF	0.942784	82	0.00	0.858583	42	0.00
Pharmaceutical Manufacturing Projects	SGPA	0.940415	58	0.01	0.959874	26	0.39
	CGPA	0.969866	44	0.30	0.829623	20	0.00
	PSG	0.953487	55	0.03	0.891345	26	0.01
	PCG	0.93372	58	0.00	0.987535	28	0.98
	PCCF	0.884815	48	0.00	0.916612	24	0.05
Grass roots	SGPA	0.933275	60	0.00	0.859382	34	0.00
	CGPA	0.960173	50	0.09	0.915916	21	0.07
	PSG	0.973284	59	0.22	0.871882	34	0.00
	PCG	0.942818	64	0.01	0.926302	33	0.03
	PCCF	0.857935	48	0.00	0.959399	25	0.40
Addition	SGPA	0.910015	73	0.00	0.940968	33	0.07
	CGPA	0.918142	62	0.00	0.960684	29	0.34
	PSG	0.949638	72	0.01	0.906521	36	0.01
	PCG	0.97942	77	0.25	0.972886	38	0.47
	PCCF	0.899555	64	0.00	0.946479	32	0.11
Modernization	SGPA	0.876117	78	0.00	0.926383	39	0.01
	CGPA	0.965089	70	0.05	0.912708	36	0.01
	PSG	0.863297	76	0.00	0.933133	37	0.03
	PCG	0.940152	81	0.00	0.946147	42	0.05
	PCCF	0.955304	72	0.01	0.905317	37	0.00
$10MM-$50MM	SGPA	0.889789	96	0.00	0.942088	39	0.04
	CGPA	0.922235	85	0.00	0.951597	37	0.11
	PSG	0.914731	93	0.00	0.907419	41	0.00
	PCG	0.958028	104	0.00	0.971264	43	0.35
	PCCF	0.938598	84	0.00	0.950359	41	0.07
$50MM-$100MM	SGPA	0.859964	46	0.00	0.793174	30	0.00
	CGPA	0.969682	41	0.34	0.916773	23	0.06
	PSG	0.928507	48	0.01	0.946404	29	0.15
	PCG	0.930969	49	0.01	0.93821	32	0.07
	PCCF	0.892978	43	0.00	0.875085	26	0.00
$100MM-$500MM	SGPA	0.935433	69	0.00	0.941753	37	0.05

Category		Sequential arrangement of two phases w/o concurrency (Pattern 1)			Sequential arrangement of two phases w concurrency (Pattern 2)		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
	CGPA	0.976916	56	0.36	0.963385	26	0.46
	PSG	0.951791	66	0.01	0.919203	37	0.01
	PCG	0.954149	69	0.01	0.899381	38	0.00
	PCCF	0.867198	57	0.00	0.943307	27	0.15

2. FEP-PRO

2.1 Duration

Category		Sequential arrangement of two phases w/o concurrency (Pattern 1)			Sequential arrangement of two phases w concurrency (Pattern 2)		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
ALL	Combined Duration	0.954559	219	0.00	0.895549	124	0.00
	Combined Duration Factor	0.991707	219	0.25	0.986479	125	0.25
	Overall Duration	0.942695	219	0.00	0.878114	124	0.00
	Overall Duration Factor	0.940613	219	0.00	0.942324	125	0.00
Heavy industrial projects	Combined Duration	0.953954	127	0.00	0.851168	74	0.00
	Combined Duration Factor	0.977011	127	0.03	0.986766	75	0.63
	Overall Duration	0.943309	127	0.00	0.836534	74	0.00
	Overall Duration Factor	0.939506	127	0.00	0.954391	75	0.01
Light industrial projects	Combined Duration	0.97062	92	0.04	0.931438	50	0.01
	Combined Duration Factor	0.991097	92	0.80	0.966359	50	0.16
	Overall Duration	0.953387	92	0.00	0.917401	50	0.00
	Overall Duration Factor	0.94537	92	0.00	0.922086	50	0.00
Process	Combined Duration	0.948314	96	0.00	0.916067	59	0.00
	Combined Duration Factor	0.971757	96	0.04	0.984163	59	0.64
	Overall Duration	0.929162	96	0.00	0.90344	59	0.00
	Overall Duration Factor	0.932904	96	0.00	0.95517	59	0.03
Pharma	Combined Duration	0.960776	55	0.07	0.931692	36	0.03
	Combined Duration Factor	0.987631	55	0.84	0.959114	36	0.20
	Overall Duration	0.964695	55	0.11	0.929106	36	0.02
	Overall Duration Factor	0.938198	55	0.01	0.915817	36	0.01
Grass roots	Combined Duration	0.966081	57	0.11	0.879403	41	0.00
	Combined Duration Factor	0.979391	57	0.44	0.958279	41	0.14
	Overall Duration	0.944949	57	0.01	0.915338	40	0.01
	Overall Duration Factor	0.940718	57	0.01	0.914876	41	0.00
Addition	Combined Duration	0.941272	81	0.00	0.896083	37	0.00
	Combined Duration Factor	0.990469	81	0.82	0.966832	37	0.33
	Overall Duration	0.909721	81	0.00	0.846625	37	0.00
	Overall Duration Factor	0.937734	81	0.00	0.958808	37	0.19
Modernization	Combined Duration	0.930045	81	0.00	0.912989	46	0.00
	Combined Duration Factor	0.970162	81	0.06	0.987053	47	0.88
	Overall Duration	0.93671	81	0.00	0.819515	47	0.00
	Overall Duration Factor	0.929438	81	0.00	0.935063	47	0.01
$10MM-50MM	Combined Duration	0.92371	102	0.00	0.891343	52	0.00

Category		Sequential arrangement of two phases w/o concurrency (Pattern 1)			Sequential arrangement of two phases w concurrency (Pattern 2)		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
	Combined Duration Factor	0.98597	102	0.36	0.978163	53	0.44
	Overall Duration	0.914337	102	0.00	0.783247	53	0.00
	Overall Duration Factor	0.940702	102	0.00	0.953545	53	0.04
$50MM-100MM	Combined Duration	0.915985	49	0.00	0.76467	28	0.00
	Combined Duration Factor	0.982139	49	0.66	0.954528	28	0.26
	Overall Duration	0.902223	49	0.00	0.871326	27	0.00
	Overall Duration Factor	0.932535	49	0.01	0.947581	28	0.17
$100MM-500MM	Combined Duration	0.969621	68	0.10	0.946894	44	0.04
	Combined Duration Factor	0.976672	68	0.23	0.962814	44	0.17
	Overall Duration	0.947135	68	0.01	0.929265	44	0.01
	Overall Duration Factor	0.926927	68	0.00	0.929627	44	0.01

2.2 Performance

Category		Sequential arrangement of two phases w/o concurrency (Pattern 1)			Sequential arrangement of two phases w concurrency (Pattern 2)		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
ALL	SGPA	0.916147	129	0.00	0.948453	68	0.01
	CGPA	0.982508	129	0.10	0.950137	68	0.01
	PSG	0.937899	129	0.00	0.964286	68	0.05
	PCG	0.987336	129	0.28	0.947389	68	0.01
	PCCF	0.911901	129	0.00	0.94245	68	0.00
Heavy Industrial projects	SGPA	0.8998	83	0.00	0.922942	45	0.01
	CGPA	0.980986	83	0.26	0.984408	45	0.80
	PSG	0.94148	83	0.00	0.949223	45	0.05
	PCG	0.975961	83	0.12	0.936174	45	0.02
	PCCF	0.929154	83	0.00	0.922946	45	0.01
Light Industrial Projects	SGPA	0.92383	46	0.01	0.95546	23	0.38
	CGPA	0.965712	46	0.19	0.844021	23	0.00
	PSG	0.887756	46	0.00	0.974086	23	0.79
	PCG	0.977658	46	0.51	0.940058	23	0.18
	PCCF	0.901156	46	0.00	0.951731	23	0.32
Process Projects	SGPA	0.91648	62	0.00	0.878735	36	0.00
	CGPA	0.974271	62	0.22	0.980732	36	0.77
	PSG	0.964074	62	0.07	0.937891	36	0.04
	PCG	0.978967	62	0.36	0.933315	36	0.03
	PCCF	0.925843	62	0.00	0.871459	36	0.00
Pharmaceutical Manufacturing Projects	SGPA	0.964261	27	0.46	0.921233	17	0.15
	CGPA	0.956358	27	0.30	0.820904	17	0.00
	PSG	0.846374	27	0.00	0.946933	17	0.41
	PCG	0.990193	27	0.99	0.931853	17	0.23
	PCCF	0.891514	27	0.01	0.95208	17	0.49
Grass roots	SGPA	0.82103	30	0.00	0.818741	18	0.00
	CGPA	0.957554	30	0.27	0.895928	18	0.05
	PSG	0.930702	30	0.05	0.962744	18	0.66
	PCG	0.953702	30	0.21	0.92834	18	0.18
	PCCF	0.876608	30	0.00	0.942125	18	0.31
Addition	SGPA	0.91019	50	0.00	0.932491	18	0.21
	CGPA	0.981838	50	0.63	0.963789	18	0.68

Category		Sequential arrangement of two phases w/o concurrency (Pattern 1)			Sequential arrangement of two phases w concurrency (Pattern 2)		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
	PSG	0.963641	50	0.13	0.926923	18	0.17
	PCG	0.984565	50	0.75	0.979475	18	0.94
	PCCF	0.915585	50	0.00	0.891491	18	0.04
Modernization	SGPA	0.936978	49	0.01	0.96824	32	0.45
	CGPA	0.963037	49	0.13	0.894166	32	0.00
	PSG	0.886452	49	0.00	0.93884	32	0.07
	PCG	0.950404	49	0.04	0.885437	32	0.00
	PCCF	0.929542	49	0.01	0.922137	32	0.02
$10MM-$50MM	SGPA	0.916859	60	0.00	0.961863	30	0.35
	CGPA	0.953443	60	0.02	0.84896	30	0.00
	PSG	0.93161	60	0.00	0.938369	30	0.08
	PCG	0.984871	60	0.66	0.971996	30	0.60
	PCCF	0.904925	60	0.00	0.898735	30	0.01
$50MM-$100MM	SGPA	0.927645	32	0.03	0.946866	17	0.41
	CGPA	0.950186	32	0.15	0.977456	17	0.93
	PSG	0.970585	32	0.52	0.876116	17	0.03
	PCG	0.911827	32	0.01	0.941876	17	0.34
	PCCF	0.934894	32	0.05	0.896907	17	0.06
$100MM-$500MM	SGPA	0.865866	37	0.00	0.906419	21	0.05
	CGPA	0.973465	37	0.51	0.955128	21	0.42
	PSG	0.904584	37	0.00	0.966177	21	0.65
	PCG	0.942153	37	0.05	0.90155	21	0.04
	PCCF	0.850188	37	0.00	0.926126	21	0.12

3. ENG-PRO

3.1 Duration

Category		Sequential arrangement of two phases w/ concurrency (Pattern 2)			Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor (Pattern 4)			Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor (Pattern 8)		
		Shapiro-Wilk			Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.	Statistic	df	Sig.
ALL	Combined Duration	0.928592	125	0.00	0.877688	38	0.00	0.893289	62	0.00
	Combined Duration Factor	0.963434	125	0.00	0.991087	38	0.99	0.977764	62	0.32
	Overall Duration	0.926989	125	0.00	0.890834	38	0.00	0.911676	62	0.00
	Overall Duration Factor	0.988109	125	0.35	0.972233	38	0.46	0.976793	62	0.29
Heavy	Combined Duration	0.90597	57	0.00	0.849093	31	0.00	0.849844	32	0.00
	Combined Duration Factor	0.953778	57	0.03	0.970676	31	0.54	0.967013	32	0.42
	Overall Duration	0.90975	57	0.00	0.877319	31	0.00	0.886961	32	0.00
	Overall Duration Factor	0.985676	57	0.73	0.962655	31	0.34	0.972597	32	0.57
Light	Combined Duration	0.944259	68	0.00	0.972758	7	0.92	0.932334	30	0.06
	Combined Duration Factor	0.972869	68	0.14	0.898287	7	0.32	0.927588	30	0.04
	Overall Duration	0.947567	68	0.01	0.94068	7	0.64	0.917637	30	0.02
	Overall Duration Factor	0.974372	68	0.17	0.844036	7	0.11	0.945865	30	0.13
Process	Combined Duration	0.954883	36	0.15	0.832533	26	0.00	0.930443	25	0.09
	Combined Duration Factor	0.990381	36	0.99	0.94292	26	0.16	0.975855	25	0.79
	Overall Duration	0.937187	36	0.04	0.864459	26	0.00	0.90189	25	0.02
	Overall Duration Factor	0.981428	36	0.79	0.958448	26	0.36	0.97417	25	0.75
Pharma	Combined Duration	0.951974	40	0.09	0.941414	4	0.66	0.9447	26	0.17
	Combined Duration Factor	0.943425	40	0.05	0.873403	4	0.31	0.951487	26	0.25
	Overall Duration	0.965692	40	0.26	0.875361	4	0.32	0.925317	26	0.06
	Overall Duration Factor	0.959459	40	0.16	0.934064	4	0.62	0.946711	26	0.19
GR	Combined Duration	0.942163	41	0.04	0.833759	7	0.09	0.865079	22	0.01
	Combined Duration Factor	0.962821	41	0.20	0.944127	7	0.68	0.93632	22	0.17
	Overall Duration	0.937296	41	0.03	0.817395	7	0.06	0.863244	22	0.01
	Overall Duration Factor	0.91674	41	0.01	0.932319	7	0.57	0.961504	22	0.52
ADD	Combined Duration	0.944738	43	0.04	0.886387	17	0.04	0.902767	18	0.06
	Combined Duration Factor	0.968255	43	0.27	0.928166	17	0.20	0.971385	18	0.82
	Overall Duration	0.892218	43	0.00	0.878429	17	0.03	0.938733	18	0.28
	Overall Duration Factor	0.976583	43	0.52	0.964475	17	0.72	0.96911	18	0.78
MOD	Combined Duration	0.930088	41	0.01	0.787868	14	0.00	0.918375	22	0.07
	Combined Duration Factor	0.917844	41	0.01	0.927937	14	0.29	0.938335	22	0.18

Category		Sequential arrangement of two phases w/ concurrency (Pattern 2)			Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor (Pattern 4)			Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor (Pattern 8)		
		Shapiro-Wilk			Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.	Statistic	df	Sig.
	Overall Duration	0.940736	41	0.03	0.854874	14	0.03	0.927709	22	0.11
	Overall Duration Factor	0.987534	41	0.93	0.919814	14	0.22	0.946284	22	0.27
$10MM-50MM	Combined Duration	0.906762	55	0.00	0.82497	20	0.00	0.93254	23	0.12
	Combined Duration Factor	0.940359	55	0.01	0.983317	20	0.97	0.920362	23	0.07
	Overall Duration	0.879342	55	0.00	0.899577	20	0.04	0.92428	23	0.08
	Overall Duration Factor	0.985253	55	0.73	0.931929	20	0.17	0.932771	23	0.13
$50MM-100MM	Combined Duration	0.838806	31	0.00	0.883439	6	0.29	0.772877	15	0.00
	Combined Duration Factor	0.984393	31	0.92	0.950444	6	0.74	0.950608	15	0.53
	Overall Duration	0.838765	31	0.00	0.874967	6	0.25	0.789968	15	0.00
	Overall Duration Factor	0.975284	31	0.67	0.963934	6	0.85	0.914682	15	0.16
$100MM-500MM	Combined Duration	0.972326	39	0.44	0.883131	12	0.10	0.916565	24	0.05
	Combined Duration Factor	0.947706	39	0.07	0.967982	12	0.89	0.953672	24	0.32
	Overall Duration	0.979793	39	0.70	0.928273	12	0.36	0.869378	24	0.01
	Overall Duration Factor	0.940452	39	0.04	0.934948	12	0.44	0.957093	24	0.38

3.2 Performance

Category		Sequential arrangement of two phases w/ concurrency (Pattern 2)			Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor (Pattern 4)			Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor (Pattern 8)		
		Shapiro-Wilk			Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.	Statistic	df	Sig.
ALL	SGPA	0.93511	119	0.00	0.945787	39	0.06	0.903538	61	0.00
	CGPA	0.935845	97	0.00	0.970663	39	0.39	0.983376	49	0.71
	PSG	0.92246	113	0.00	0.943922	39	0.05	0.927009	59	0.00
	PCG	0.975335	118	0.03	0.972646	40	0.43	0.952821	61	0.02
	PCCF	0.877074	103	0.00	0.963429	37	0.26	0.858242	52	0.00
Heavy Industrial projects	SGPA	0.931304	56	0.00	0.944746	32	0.10	0.881934	31	0.00
	CGPA	0.946882	50	0.03	0.986664	32	0.95	0.979911	28	0.85
	PSG	0.882029	53	0.00	0.95597	33	0.20	0.869948	31	0.00
	PCG	0.988944	54	0.90	0.964076	33	0.34	0.958252	31	0.26
	PCCF	0.868782	46	0.00	0.950367	32	0.15	0.921628	24	0.06
Light Industrial Projects	SGPA	0.925153	63	0.00	0.914066	7	0.42	0.919892	30	0.03
	CGPA	0.914585	47	0.00	0.852212	7	0.13	0.971681	21	0.77
	PSG	0.931207	60	0.00	0.824894	6	0.10	0.930817	28	0.06
	PCG	0.937066	64	0.00	0.989241	7	0.99	0.950786	30	0.18
	PCCF	0.894178	57	0.00	0.962585	5	0.83	0.871122	28	0.00

Category		Sequential arrangement of two phases w/ concurrency (Pattern 2)			Parallel arrangement of two phases w/ concurrency and longer duration of a predecessor (Pattern 4)			Reversed sequential arrangement of two phases w/ concurrency and longer duration of a successor (Pattern 8)		
		Shapiro-Wilk			Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.	Statistic	df	Sig.
Process Projects	SGPA	0.929081	35	0.03	0.944704	26	0.17	0.872326	24	0.01
	CGPA	0.900952	33	0.01	0.975271	25	0.78	0.948666	24	0.25
	PSG	0.913664	32	0.01	0.975488	26	0.77	0.923346	24	0.07
	PCG	0.971915	34	0.52	0.952385	26	0.26	0.964676	26	0.49
	PCCF	0.827373	29	0.00	0.947857	25	0.22	0.933207	21	0.16
Pharmaceutical Manufacturing Projects	SGPA	0.927324	35	0.02	0.982608	4	0.92	0.939374	26	0.13
	CGPA	0.923561	28	0.04	0.808914	4	0.12	0.965496	17	0.74
	PSG	0.923333	35	0.02	0.999874	3	0.98	0.925274	24	0.08
	PCG	0.948778	36	0.10	0.976566	4	0.88	0.947015	26	0.20
	PCCF	0.886953	31	0.00	0	0	0.00	0.892438	24	0.01
Grass roots	SGPA	0.81748	22	0.00	0.779715	6	0.04	0.874737	16	0.03
	CGPA	0.944153	16	0.40	0.883563	5	0.33	0.983054	11	0.98
	PSG	0.891605	20	0.03	0.930993	6	0.59	0.915239	16	0.14
	PCG	0.936305	21	0.18	0.882334	6	0.28	0.985365	16	0.99
	PCCF	0.877741	17	0.03	0.734024	4	0.03	0.910223	13	0.18
Addition	SGPA	0.924793	23	0.08	0.961737	13	0.78	0.917379	15	0.18
	CGPA	0.898243	22	0.03	0.911168	13	0.19	0.953694	12	0.69
	PSG	0.941787	23	0.20	0.977181	13	0.96	0.941056	14	0.43
	PCG	0.946234	24	0.22	0.933065	13	0.37	0.923041	16	0.19
	PCCF	0.823996	20	0.00	0.922411	13	0.27	0.725098	14	0.00
Modernization	SGPA	0.94617	25	0.21	0.87536	11	0.09	0.928283	19	0.16
	CGPA	0.971522	23	0.73	0.898576	11	0.18	0.954691	18	0.50
	PSG	0.969688	24	0.66	0.938503	10	0.54	0.885738	18	0.03
	PCG	0.973302	25	0.73	0.938266	11	0.50	0.901934	20	0.04
	PCCF	0.890437	23	0.02	0.982262	10	0.98	0.931278	18	0.20
$10MM-$50MM	SGPA	0.886384	35	0.00	0.90503	17	0.08	0.912048	16	0.13
	CGPA	0.927991	31	0.04	0.911123	17	0.10	0.976713	13	0.96
	PSG	0.880786	32	0.00	0.954204	16	0.56	0.892359	15	0.07
	PCG	0.981794	33	0.84	0.938181	17	0.30	0.972801	17	0.87
	PCCF	0.858111	30	0.00	0.912266	17	0.11	0.922409	13	0.27
$50MM-$100MM	SGPA	0.897489	14	0.10	0.985632	4	0.93	0.866271	14	0.04
	CGPA	0.839578	14	0.02	0.817212	4	0.14	0.931613	11	0.43
	PSG	0.935767	15	0.33	0.925746	4	0.57	0.788341	13	0.00
	PCG	0.931943	17	0.23	0.98976	4	0.96	0.922089	14	0.24
	PCCF	0.816931	14	0.01	0.811875	4	0.13	0.729451	13	0.00
$100MM-$500MM	SGPA	0.861086	21	0.01	0.919126	9	0.39	0.913342	20	0.07
	CGPA	0.946036	16	0.43	0.944512	8	0.66	0.886366	17	0.04
	PSG	0.910422	20	0.06	0.940616	9	0.59	0.934713	20	0.19
	PCG	0.945152	20	0.30	0.874943	9	0.14	0.92528	21	0.11
	PCCF	0.806645	16	0.00	0.89233	6	0.33	0.881075	19	0.02

4. DE-CON

4.1 Duration

Category		Sequential arrangement of two phases w/o concurrency (Pattern 1)			Sequential arrangement of two phases w concurrency (Pattern 2)		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
ALL	Combined Duration	0.882902	50	0.00	0.912832	281	0.00
	Combined Duration Factor	0.965564	50	0.15	0.99395	282	0.32
	Overall Duration	0.873241	50	0.00	0.925529	280	0.00
	Overall Duration Factor	0.96952	50	0.22	0.986328	282	0.01
Heavy industrial projects	Combined Duration	0.927268	27	0.06	0.878144	167	0.00
	Combined Duration Factor	0.910843	27	0.02	0.992075	168	0.49
	Overall Duration	0.923937	27	0.05	0.892022	166	0.00
	Overall Duration Factor	0.962244	27	0.42	0.988741	168	0.20
Light Industrial Projects	Combined Duration	0.770442	23	0.00	0.960239	114	0.00
	Combined Duration Factor	0.967787	23	0.64	0.990884	114	0.65
	Overall Duration	0.773035	23	0.00	0.956049	114	0.00
	Overall Duration Factor	0.962063	23	0.51	0.958695	114	0.00
Modernization	Combined Duration	0.893564	28	0.01	0.901725	98	0.00
	Combined Duration Factor	0.98007	28	0.85	0.980261	98	0.15
	Overall Duration	0.895387	28	0.01	0.914961	97	0.00
	Overall Duration Factor	0.954231	28	0.25	0.981948	98	0.20
$10MM-50MM	Combined Duration	0.907932	34	0.01	0.900985	114	0.00
	Combined Duration Factor	0.940181	34	0.06	0.988914	114	0.48
	Overall Duration	0.896168	34	0.00	0.88012	114	0.00
	Overall Duration Factor	0.959224	34	0.23	0.985808	114	0.27

4.2 Performance

Category		Sequential arrangement of two phases w/o concurrency (Pattern 1)			Sequential arrangement of two phases w concurrency (Pattern 2)		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
All	SGPA	0.916989	49	0.00207	0.945468	269	1.88E-08
	CGPA	0.966506	44	0.22662	0.987043	251	0.022943
	PSG	0.945954	47	0.030125	0.937591	254	6.64E-09
	PCG	0.923442	49	0.00352	0.976478	273	0.000178
	PCCF	0.935963	42	0.020693	0.925087	226	2.69E-09
	SGPA	0.861315	26	0.002377	0.943864	160	5.54E-06
Heavy Industrial Projects	CGPA	0.992551	22	0.999639	0.989427	154	0.300972
	PSG	0.894492	24	0.01648	0.921391	154	1.93E-07
	PCG	0.941152	26	0.143092	0.980892	164	0.023052
	PCCF	0.959019	20	0.52444	0.925398	135	1.51E-06
Light Industrial Projects	SGPA	0.940612	23	0.185234	0.94792	109	0.000323

Category		Sequential arrangement of two phases w/o concurrency (Pattern 1)			Sequential arrangement of two phases w concurrency (Pattern 2)		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
	CGPA	0.867162	22	0.006935	0.978028	97	0.103335
	PSG	0.961374	23	0.491678	0.937223	100	0.000131
	PCG	0.881369	23	0.01065	0.960698	109	0.002682
	PCCF	0.884673	22	0.014853	0.931843	91	0.000137
Modernization	SGPA	0.929156	27	0.065897	0.945034	92	0.000719
	CGPA	0.972766	26	0.695833	0.971233	93	0.037711
	PSG	0.867391	26	0.003153	0.900888	84	8.51E-06
	PCG	0.899058	27	0.012729	0.960194	95	0.005582
	PCCF	0.855041	25	0.002199	0.945839	83	0.001592
$10MM-$50MM	SGPA	0.88339	34	0.001718	0.934344	107	5.02E-05
	CGPA	0.982179	29	0.889679	0.981795	105	0.15935
	PSG	0.919585	32	0.020259	0.911062	98	5.92E-06
	PCG	0.921606	33	0.020303	0.974018	112	0.027712
	PCCF	0.94589	28	0.156017	0.934862	94	0.000156

5. PRO-CON

5.1 Duration

Category		Sequential arrangement of two phases w/o concurrency (Pattern 1)			Sequential arrangement of two phases w concurrency (Pattern 2)		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
ALL	Combined Duration	0.829803	28	0.00	0.937731	274	0.00
	Combined Duration Factor	0.959198	28	0.33	0.989892	274	0.05
	Overall Duration	0.866823	28	0.00	0.953144	274	0.00
	Overall Duration Factor	0.967396	28	0.51	0.989915	274	0.05
Heavy industrial projects	Combined Duration	0.845711	21	0.00	0.905776	166	0.00
	Combined Duration Factor	0.951728	21	0.37	0.98401	166	0.05
	Overall Duration	0.879701	21	0.01	0.941812	166	0.00
	Overall Duration Factor	0.97012	21	0.74	0.989149	166	0.23

5.2 Performance

Category		Sequential arrangement of two phases w/o concurrency (Pattern 1)			Sequential arrangement of two phases w concurrency (Pattern 2)		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
All	SGPA	0.932145	27	0.08	0.940902	258	0.00
	CGPA	0.948987	21	0.33	0.966686	224	0.00
	PSG	0.875266	27	0.00	0.934192	247	0.00
	PCG	0.956145	28	0.28	0.967143	264	0.00
	PCCF	0.909374	22	0.05	0.931046	215	0.00
Heavy Industrial Projects	SGPA	0.914491	20	0.08	0.924119	156	0.00
	CGPA	0.927097	17	0.19	0.965061	145	0.00
	PSG	0.861906	20	0.01	0.890629	150	0.00
	PCG	0.959265	21	0.50	0.975963	161	0.01
	PCCF	0.88566	15	0.06	0.959395	129	0.00

6. CON-ST

6.1 Duration

Category		Sequential arrangement of two phases w/o concurrency (Pattern 1)			Sequential arrangement of two phases w concurrency (Pattern 2)		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
All	Combined Duration	0.905504	146	0.00	0.916223	145	0.00
	Combined Duration Factor	0.988787	146	0.29	0.98744	146	0.21
	Overall Duration	0.916446	146	0.00	0.93748	145	0.00
	Overall Duration Factor	0.990726	146	0.45	0.988795	146	0.29
Heavy industrial Projects	Combined Duration	0.915599	127	0.00	0.838086	45	0.00
	Combined Duration Factor	0.987502	127	0.30	0.969532	45	0.28
	Overall Duration	0.922912	127	0.00	0.841877	45	0.00
	Overall Duration Factor	0.990899	127	0.58	0.984169	45	0.79
Process Projects	Combined Duration	0.932398	94	0.00	0.82051	33	0.00
	Combined Duration Factor	0.992694	94	0.89	0.966825	33	0.40
	Overall Duration	0.938072	94	0.00	0.805142	33	0.00
	Overall Duration Factor	0.986188	94	0.43	0.972849	33	0.56
Grass Roots	Combined Duration	0.899761	37	0.00	0.926969	56	0.00
	Combined Duration Factor	0.98435	37	0.87	0.989266	57	0.89
	Overall Duration	0.906386	37	0.00	0.95558	56	0.04
	Overall Duration Factor	0.968089	37	0.36	0.991258	57	0.95
Addition	Combined Duration	0.896825	52	0.00	0.878076	44	0.00
	Combined Duration Factor	0.983523	52	0.68	0.934549	44	0.02
	Overall Duration	0.917418	52	0.00	0.83047	44	0.00
	Overall Duration Factor	0.970874	52	0.23	0.970707	44	0.32
Modernization	Combined Duration	0.847066	57	0.00	0.907024	45	0.00
	Combined Duration Factor	0.985122	57	0.71	0.960898	45	0.13
	Overall Duration	0.856204	57	0.00	0.926932	45	0.01
	Overall Duration Factor	0.971465	57	0.20	0.96305	45	0.16
$10MM-50MM	Combined Duration	0.924593	81	0.00	0.903148	47	0.00
	Combined Duration Factor	0.988578	81	0.70	0.962896	47	0.14
	Overall Duration	0.935321	81	0.00	0.968948	47	0.24
	Overall Duration Factor	0.98407	81	0.41	0.974167	47	0.38
$50MM-100MM	Combined Duration	0.835899	26	0.00	0.915856	39	0.01
	Combined Duration Factor	0.969757	26	0.62	0.9776	39	0.62
	Overall Duration	0.866425	26	0.00	0.938923	39	0.04
	Overall Duration Factor	0.96949	26	0.61	0.944881	39	0.06
$100MM-500MM	Combined Duration	0.956615	39	0.14	0.957468	59	0.04
	Combined Duration Factor	0.963508	39	0.23	0.985954	60	0.72
	Overall Duration	0.956483	39	0.14	0.976358	59	0.30
	Overall Duration Factor	0.955788	39	0.13	0.966142	60	0.09

6.2 Performance

Category		Sequential arrangement of two phases w/o concurrency (Pattern 1)			Sequential arrangement of two phases w concurrency (Pattern 2)		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
All	Combined Duration	0.905504	146	0.00	0.916223	145	0.00
	Combined Duration Factor	0.988787	146	0.29	0.98744	146	0.21
	Overall Duration	0.916446	146	0.00	0.93748	145	0.00
	Overall Duration Factor	0.990726	146	0.45	0.988795	146	0.29
Heavy industrial Projects	Combined Duration	0.915599	127	0.00	0.838086	45	0.00
	Combined Duration Factor	0.987502	127	0.30	0.969532	45	0.28
	Overall Duration	0.922912	127	0.00	0.841877	45	0.00
	Overall Duration Factor	0.990899	127	0.58	0.984169	45	0.79
Process Projects	Combined Duration	0.932398	94	0.00	0.82051	33	0.00
	Combined Duration Factor	0.992694	94	0.89	0.966825	33	0.40
	Overall Duration	0.938072	94	0.00	0.805142	33	0.00
	Overall Duration Factor	0.986188	94	0.43	0.972849	33	0.56
Grass Roots	Combined Duration	0.899761	37	0.00	0.926969	56	0.00
	Combined Duration Factor	0.98435	37	0.87	0.989266	57	0.89
	Overall Duration	0.906386	37	0.00	0.95558	56	0.04
	Overall Duration Factor	0.968089	37	0.36	0.991258	57	0.95
Addition	Combined Duration	0.896825	52	0.00	0.878076	44	0.00
	Combined Duration Factor	0.983523	52	0.68	0.934549	44	0.02
	Overall Duration	0.917418	52	0.00	0.83047	44	0.00
	Overall Duration Factor	0.970874	52	0.23	0.970707	44	0.32
Modernization	Combined Duration	0.847066	57	0.00	0.907024	45	0.00
	Combined Duration Factor	0.985122	57	0.71	0.960898	45	0.13
	Overall Duration	0.856204	57	0.00	0.926932	45	0.01
	Overall Duration Factor	0.971465	57	0.20	0.96305	45	0.16
$10MM-50MM	Combined Duration	0.924593	81	0.00	0.903148	47	0.00
	Combined Duration Factor	0.988578	81	0.70	0.962896	47	0.14
	Overall Duration	0.935321	81	0.00	0.968948	47	0.24
	Overall Duration Factor	0.98407	81	0.41	0.974167	47	0.38
$50MM-100MM	Combined Duration	0.835899	26	0.00	0.915856	39	0.01
	Combined Duration Factor	0.969757	26	0.62	0.9776	39	0.62
	Overall Duration	0.866425	26	0.00	0.938923	39	0.04
	Overall Duration Factor	0.96949	26	0.61	0.944881	39	0.06
$100MM-500MM	Combined Duration	0.956615	39	0.14	0.957468	59	0.04
	Combined Duration Factor	0.963508	39	0.23	0.985954	60	0.72
	Overall Duration	0.956483	39	0.14	0.976358	59	0.30
	Overall Duration Factor	0.955788	39	0.13	0.966142	60	0.09

7. FEP-DE-PRO

7.1 Duration

Category		Pattern 2 (1-1-2)			Pattern 3 (1-1-4)		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
All	Combined Duration	0.971619	78	0.08	0.959088	22	0.47
	Combined Duration Factor	0.982054	79	0.33	0.943198	22	0.23
	Overall Duration	0.955913	79	0.01	0.95186	22	0.34
	Overall Duration Factor	0.890332	79	0.00	0.950261	22	0.32
Heavy industrial Projects	Combined Duration	0.951225	35	0.12	0.963394	20	0.61
	Combined Duration Factor	0.964425	36	0.29	0.93079	20	0.16
	Overall Duration	0.918465	36	0.01	0.944411	20	0.29
	Overall Duration Factor	0.853315	36	0.00	0.960827	20	0.56

7.2 Performance

Category		Pattern 2 (1-1-2)			Pattern 3 (1-1-4)		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
All	SGPA	0.927195	71	0.00	0.84564	21	0.00
	CGPA	0.951453	60	0.02	0.98039	19	0.95
	PSG	0.89796	70	0.00	0.954337	22	0.38
	PCG	0.964486	74	0.04	0.931309	22	0.13
	PCCF	0.852727	63	0.00	0.969337	21	0.72
Heavy Industrial Projects	SGPA	0.855178	32	0.00	0.835228	19	0.00
	CGPA	0.970924	30	0.56	0.974532	18	0.88
	PSG	0.816427	32	0.00	0.963589	20	0.62
	PCG	0.976043	33	0.66	0.922372	20	0.11
	PCCF	0.918719	28	0.03	0.959734	19	0.57

8. DE-PRO-CON

8.1 Duration

Category		Pattern 9 (2-2-2)			Pattern 12 (4-2-2)			Pattern 14 (8-2-2)		
		Shapiro-Wilk			Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.	Statistic	df	Sig.
All	Combined Duration	0.920199	78	0.00	0.854466	31	0.00	0.957503	46	0.09
	Combined Duration Factor	0.924791	78	0.00	0.970462	31	0.53	0.973961	48	0.36
	Overall Duration	0.943592	78	0.00	0.862355	31	0.00	0.942371	46	0.02
	Overall Duration Factor	0.950274	78	0.00	0.942043	31	0.09	0.969961	48	0.25
Heavy Industrial Projects	Combined Duration	0.866883	34	0.00	0.845899	25	0.00	0.929003	27	0.07
	Combined Duration Factor	0.92523	34	0.02	0.952171	25	0.28	0.950694	29	0.19
	Overall Duration	0.897492	34	0.00	0.85835	25	0.00	0.926581	27	0.06
	Overall Duration Factor	0.972534	34	0.53	0.949606	25	0.25	0.969862	29	0.56
Process Projects	Combined Duration	0.774003	25	0.00				0.896874	23	0.02
	Combined Duration Factor	0.91618	25	0.04				0.950383	23	0.30
	Overall Duration	0.797479	25	0.00				0.900507	23	0.03
	Overall Duration Factor	0.937544	25	0.13				0.970433	23	0.70

8.2 Performance

Category		Pattern 9 (2-2-2)			Pattern 12 (4-2-2)			Pattern 14 (8-2-2)		
		Shapiro-Wilk			Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.	Statistic	df	Sig.
All	SGPA	0.870372	77	0.00	0.968788	31	0.49	0.916637	48	0.00
	CGPA	0.885202	78	0.00	0.938066	31	0.07	0.939469	48	0.02
	PSG	0.868845	76	0.00	0.962289	30	0.35	0.904186	46	0.00
	PCG	0.957476	72	0.02	0.965973	31	0.42	0.951612	46	0.05
	PCCF	0.833422	61	0.00	0.948542	30	0.15	0.930854	37	0.02
Heavy Industrial Projects	SGPA	0.861254	34	0.00	0.971122	25	0.67	0.924793	29	0.04
	CGPA	0.9241	34	0.02	0.91384	25	0.04	0.956266	29	0.27
	PSG	0.789706	34	0.00	0.975379	24	0.80	0.883205	29	0.00
	PCG	0.984883	31	0.93	0.953601	25	0.30	0.961779	27	0.41
	PCCF	0.871203	26	0.00	0.942928	25	0.17	0.913044	21	0.06
Process Projects	SGPA	0.872043	25	0.00				0.97593	19	0.89
	CGPA	0.920418	23	0.07				0.862307	25	0.00
	PSG	0.876301	19	0.02				0.955266	23	0.37
	PCG	0.76645	25	0.00				0.981404	19	0.96
	PCCF	0.925557	23	0.09				0.945642	23	0.24

9. PRO-CON-ST

9.1 Duration

Category		Pattern 6 (2-1-1)			Pattern 7 (2-1-2)		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
All	Combined Duration	0.908067	112	0.00	0.920752	74	0.00
	Combined Duration Factor	0.978496	112	0.07	0.983532	74	0.45
	Overall Duration	0.944854	112	0.00	0.932688	73	0.00
	Overall Duration Factor	0.981224	112	0.12	0.955193	74	0.01
Heavy Industrial Projects	Combined Duration	0.902241	99	0.00	0.881303	29	0.00
	Combined Duration Factor	0.970099	99	0.02	0.979671	29	0.83
	Overall Duration	0.949619	99	0.00	0.907086	29	0.01
	Overall Duration Factor	0.985817	99	0.37	0.935781	29	0.08
Process Projects	Combined Duration	0.915271	76	0.00	0.982066	21	0.95
	Combined Duration Factor	0.970584	76	0.07	0.970323	21	0.74
	Overall Duration	0.97152	76	0.08	0.939888	21	0.22
	Overall Duration Factor	0.98698	76	0.63	0.928645	21	0.13
Grass Roots	Combined Duration	0.889327	26	0.01	0.921821	35	0.02
	Combined Duration Factor	0.96734	26	0.56	0.979925	35	0.76
	Overall Duration	0.90327	26	0.02	0.962074	34	0.28
	Overall Duration Factor	0.977529	26	0.82	0.938432	35	0.05
Addition	Combined Duration	0.894827	42	0.00	0.735705	21	0.00
	Combined Duration Factor	0.985802	42	0.87	0.960939	21	0.54
	Overall Duration	0.936105	42	0.02	0.701555	21	0.00
	Overall Duration Factor	0.952694	42	0.08	0.953913	21	0.40
$10MM-$50MM	Combined Duration	0.916911	62	0.00	0.941519	23	0.19
	Combined Duration Factor	0.978756	62	0.36	0.933186	23	0.13
	Overall Duration	0.92428	62	0.00	0.923851	23	0.08
	Overall Duration Factor	0.967102	62	0.09	0.977185	23	0.85
$100MM-$500MM	Combined Duration	0.964142	30	0.39	0.876271	33	0.00
	Combined Duration Factor	0.968455	30	0.50	0.980523	33	0.80
	Overall Duration	0.936778	30	0.07	0.915308	32	0.02
	Overall Duration Factor	0.964471	30	0.40	0.928976	33	0.03

9.2 Performance

Category		Pattern 6 (2-1-1)			Pattern 7 (2-1-2)		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
All	SGPA	0.856809	88	0.00	0.879583	70	0.00
	CGPA	0.965111	64	0.07	0.919817	51	0.00
	PSG	0.89094	98	0.00	0.901036	70	0.00
	PCG	0.97826	107	0.08	0.932177	71	0.00
	PCCF	0.913712	82	0.00	0.923749	58	0.00
Heavy Industrial Projects	SGPA	0.863353	79	0.00	0.87453	28	0.00
	CGPA	0.964424	55	0.10	0.916083	21	0.07
	PSG	0.884336	90	0.00	0.856414	29	0.00
	PCG	0.979112	95	0.13	0.960426	29	0.34
	PCCF	0.925098	73	0.00	0.969679	24	0.66
Process Projects	SGPA	0.852285	59	0.00	0.81163	21	0.00
	CGPA	0.962171	43	0.17	0.955803	16	0.59
	PSG	0.862954	69	0.00	0.861714	21	0.01
	PCG	0.989319	74	0.79	0.957743	21	0.47
	PCCF	0.919088	58	0.00	0.978287	18	0.93
Grass Roots	SGPA	0.844869	24	0.00	0.848746	32	0.00
	CGPA	0.92294	16	0.19	0.885629	21	0.02
	PSG	0.938458	24	0.15	0.858791	32	0.00
	PCG	0.929302	24	0.09	0.90569	33	0.01
	PCCF	0.830478	16	0.01	0.887576	25	0.01
Addition	SGPA	0.916642	36	0.01	0.937982	20	0.22
	CGPA	0.945504	24	0.22	0.960073	14	0.72
	PSG	0.935263	38	0.03	0.954481	21	0.41
	PCG	0.964099	41	0.22	0.951233	21	0.36
	PCCF	0.88872	31	0.00	0.885816	17	0.04
$10MM-$50MM	SGPA	0.828791	45	0.00	0.920347	23	0.07
	CGPA	0.957824	33	0.22	0.938256	17	0.30
	PSG	0.83613	53	0.00	0.952666	22	0.36
	PCG	0.966376	59	0.10	0.971318	23	0.72
	PCCF	0.935067	45	0.01	0.955438	20	0.46
$100MM-$500MM	SGPA	0.809618	27	0.00	0.86527	30	0.00
	CGPA	0.943048	18	0.33	0.919799	23	0.07
	PSG	0.921428	28	0.04	0.878869	31	0.00
	PCG	0.932184	28	0.07	0.937917	30	0.08
	PCCF	0.867208	21	0.01	0.905869	24	0.03

Methodological Application

1. FEP-DE

Category		High Complexity			Low Complexity		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
OVER_DUR	PT1	0.923	25	0.060	0.954	32	0.191
	PT2	0.974	12	0.951	0.912	16	0.125
PCG	PT1	0.872	25	0.005	0.970	32	0.507
	PT2	0.913	12	0.235	0.928	16	0.230
PSG	PT1	0.907	21	0.048	0.890	27	0.008
	PT2	0.852	11	0.046	0.880	14	0.058
PCCF	PT1	0.854	23	0.003	0.937	23	0.152
	PT2	0.974	8	0.929	0.949	15	0.516

2. FEP-PRO

Category		High Complexity			Low Complexity		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
OVER_DUR	PT1	0.914	23	0.050	0.938	29	0.091
	PT2	0.937	14	0.385	0.959	18	0.575
PCG	PT1	0.943	22	0.233	0.924	29	0.039
	PT2	0.886	14	0.071	0.946	18	0.361
PSG	PT1	0.923	20	0.112	0.848	25	0.002
	PT2	0.913	14	0.177	0.959	15	0.671
PCCF	PT1	0.876	21	0.012	0.881	24	0.009
	PT2	0.970	11	0.890	0.920	14	0.220

2. DE-CON

Category		High Complexity			Low Complexity		
		Shapiro-Wilk			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
OVER_DUR	PT1						
	PT2	0.960	31	0.301	0.911	45	0.002
PCG	PT1						
	PT2	0.886	32	0.003	0.984	45	0.775
PSG	PT1						
	PT2	0.879	29	0.003	0.857	40	0.000
PCCF	PT1						
	PT2	0.933	26	0.092	0.956	36	0.166

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Vita

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